

CHAPTER 14

CABIN ATMOSPHERE CONTROL SYSTEM

NEED FOR OXYGEN

Oxygen is essential for most living processes. Without oxygen, men and other animals die very rapidly. But before this extreme state is reached, a reduction in normal oxygen supplies to the tissues of the body can produce important changes in body functions, thought processes, and degree of consciousness. The sluggish condition of mind and body caused by a deficiency or lack of oxygen is called hypoxia. There are several causes of hypoxia, but the one which concerns aircraft operations is the decrease in partial pressure of the oxygen in the lungs.

The rate at which the lungs absorb oxygen depends upon the oxygen pressure. The pressure that oxygen exerts is about one-fifth of the total air pressure at any one given level. At sea level, this pressure value (3 p.s.i.) is sufficient to saturate the blood. However, if the oxygen pressure is reduced, either from the reduced atmospheric pressure at altitude or because the percentage of oxygen in the air breathed decreases, then the quantity of oxygen in the blood leaving the lungs drops and hypoxia follows.

From sea level to 7,000 ft. above sea level, the oxygen content and pressure in the atmosphere remain sufficiently high to maintain almost full saturation of the blood with oxygen and thus ensure normal body and mental functions.

At high altitude there is decreased barometric pressure, resulting in decreased oxygen content of the inhaled air. Consequently, the oxygen content of the blood is reduced.

At 10,000 ft. above sea level oxygen saturation of the blood is about 90%. Long exposure at this altitude will result in headache and fatigue. Oxygen saturation drops to 81% at 15,000 ft. above sea level. This decrease results in sleepiness, headache, blue lips and fingernails, impaired vision and judgment, increased pulse and respiration, and certain personality changes.

At 22,000 ft. above sea level the blood saturation is 68% and convulsions are likely to occur. Remain-

ing without an oxygen supply at 25,000 ft. for 5 minutes where the blood saturation is down to 55 to 50% will cause unconsciousness.

COMPOSITION OF THE ATMOSPHERE

The mixture of gases commonly called air but more technically termed atmosphere is composed principally of nitrogen and oxygen, but there are smaller quantities of other important gases, notable carbon dioxide, water vapor, and ozone. Figure 14-1 indicates the respective percentage of the quantity of each gas in its relation to the total mixture.

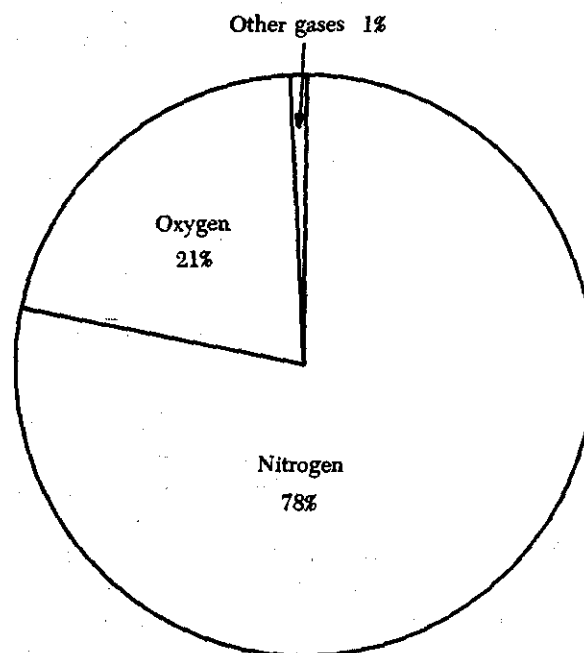


FIGURE 14-1. The gases of the atmosphere.

As the altitude increases, the total quantity of all the atmospheric gases reduces rapidly, and, except for water vapor and ozone, the relative proportions of the gaseous mixture remain unchanged up to about 50 miles altitude, or slightly above. Above 50 miles altitude, changes do take place, and different

gases and new forms of the gases present at lower altitudes appear.

Nitrogen is the most common gas and comprises 78% of the total mixture of atmospheric gases. However, insofar as man is concerned nitrogen is an inert gas which cannot be used directly for his own life processes. But biologically it is of immense importance because many compounds containing nitrogen are essential to all living matter.

Oxygen and its importance cannot be overestimated. Without oxygen, life as we know it cannot exist. Oxygen occupies 21% of the total mixture of atmospheric gases.

Carbon dioxide is of biological interest. The small quantity in the atmosphere is utilized by the plant world to manufacture the complex substance which animals use as food. Carbon dioxide also helps in the control of breathing in man and other animals.

Water vapor in the atmosphere is variable, but, even under the moist conditions at sea level, it rarely exceeds 5%; yet this gas absorbs far more energy from the sun than do the other gases. Vapor is not the only form in which water occurs in the atmosphere; water and ice particles are nearly always present. These ice particles also absorb energy and, with water vapor, play an important part in the formation of atmospheric and weather conditions.

Ozone is a variety of oxygen which contains three atoms of oxygen per molecule rather than the usual two. The major portion of the ozone in the atmosphere is formed by the interaction of oxygen and the sun's rays near the top of the ozone layer.

Ozone is also produced by electrical discharges, and the peculiar odor of ozone, which is somewhat like that of weak chlorine, can be detected after lightning storms. Auroras and cosmic rays may also produce ozone. Ozone is of great consequence to both living creatures on earth and to the circulation of the upper atmosphere. Ozone is important to living organisms because it filters out most of the sun's ultraviolet radiation.

Pressure of the Atmosphere

The gases of the atmosphere (air), although invisible, have weight just like that of solid matter. The weight of a column of air stretching from the surface of the earth out into space is called the atmospheric pressure. If this column is 1 sq. in., the weight of air at sea level is approximately 14.7 lbs.; and the atmospheric pressure, therefore, can be

stated as 14.7 p.s.i. at sea level. Another common way of stating the atmospheric pressure is to give the height of a column of mercury which weighs the same as a column of the atmosphere of the same cross sectional area. When measured this way, the atmospheric pressure at sea level is normally 1013.2 millibars, or 29.92 in. Hg.

The atmospheric pressure decreases with increasing altitude. The reason for this is quite simple: the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in figure 14-2. The decrease in pressure is a rapid one, and at 50,000 feet the atmospheric pressure has dropped to almost one-tenth of the sea level value. At a few hundred miles above the earth, the air has become so rarefied (thin) that the atmosphere can be considered nonexistent, but the line of demarcation with space is very vague.

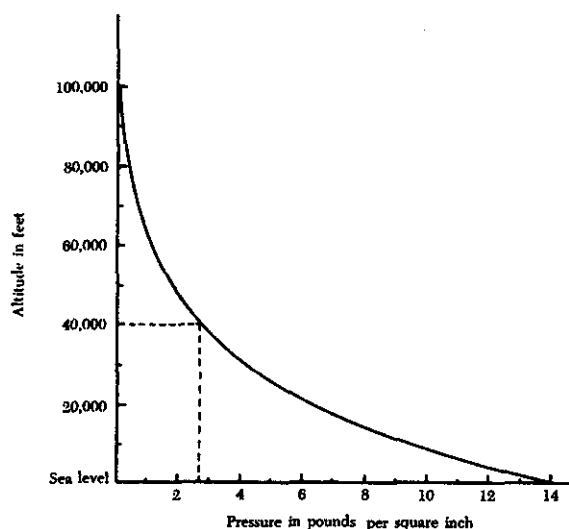


FIGURE 14-2. How the atmospheric pressure decreases with altitude. For example, at sea level the pressure is 14.7 p.s.i.; while at 40,000 ft., as the dotted lines show, the pressure is only 2.72 p.s.i.

Temperature and Altitude

The variations in atmospheric temperature near the earth are well known and need no discussion. However, at high altitudes the atmospheric temperature is not so variable but tends to have a more set pattern.

The meteorologist finds it convenient to define, somewhat arbitrarily, the atmosphere as being made up of several layers. The lowest of these is called the troposphere. The air temperature decreases with

increasing altitude in the troposphere and reaches a definite minimum at the top of the layer. The top of the troposphere is called the tropopause. The tropopause reaches its greatest height over the equator (about 60,000 ft.) and its lowest height over the poles (about 30,000 ft.). The tropopause marks the point at which air temperature stops decreasing with increasing altitude, and remains essentially constant.

The atmospheric layer above the tropopause is called the stratosphere. The lower stratosphere is an isothermal (constant temperature) region in which the temperature does not vary with altitude. The isothermal region continues up to about 82,000 to 115,000 ft. altitude. Above this level, the temperature increases sharply at the rate of about 1.5° C. per 1,000 ft. The temperature reaches a peak at about 164,000 to 197,000 ft. altitude. Above the 197,000 ft. altitude (approximately), the temperature decreases again, reaching a minimum of -10° F. to -100° F. at about 230,000 to 262,000 ft. altitude. Above this level, the temperature again increases and apparently continues to increase until the edge of space.

The foregoing paragraphs have presented a general knowledge of the atmosphere. It is obvious that a means of preventing hypoxia and its ill effects must be provided. When the atmospheric pressure falls below 3 p.s.i. (approximately 40,000 ft.), even breathing pure oxygen is not sufficient.

The low partial pressure of oxygen, low ambient air pressure, and temperature at high altitude make it necessary to create the proper environment for passenger and crew comfort. The most difficult problem is maintaining the correct partial pressure of oxygen in the inhaled air. This can be achieved by using oxygen, pressurized cabins, or pressure suits. The first and second methods are used extensively in civil aviation.

Pressurization of the aircraft cabin is now the accepted method of protecting persons against the effects of hypoxia. Within a pressurized cabin, people can be transported comfortably and safely for long periods of time, particularly if the cabin altitude is maintained at 8,000 ft., or below, where the use of oxygen equipment is not required. However, the flight crew in this type of aircraft must be aware of the danger of accidental loss of cabin pressure and must be prepared to meet such an emergency whenever it occurs.

PRESSURIZATION

When an aircraft is flown at a high altitude, it burns less fuel for a given airspeed than it does for the same speed at a lower altitude. In other words, the airplane is more efficient at a high altitude. In addition, bad weather and turbulence can be avoided by flying in the relatively smooth air above the storms. Aircraft which do not have pressurization and air conditioning systems are usually limited to the lower altitudes.

A cabin pressurization system must accomplish several functions if it is to assure adequate passenger comfort and safety. It must be capable of maintaining a cabin pressure altitude of approximately 8,000 ft. at the maximum designed cruising altitude of the aircraft. The system must also be designed to prevent rapid changes of cabin altitude which may be uncomfortable or injurious to passengers and crew. In addition, the pressurization system should permit a reasonably fast exchange of air from inside to outside the cabin. This is necessary to eliminate odors and to remove stale air.

In the typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit which is capable of containing air under a pressure higher than outside atmospheric pressure. Pressurized air is pumped into this sealed fuselage by cabin superchargers which deliver a relatively constant volume of air at all altitudes up to a designed maximum. Air is released from the fuselage by a device called an outflow valve. Since the superchargers provide a constant inflow of air to the pressurized area, the outflow valve, by regulating the air exit, is the major controlling element in the pressurization system.

The flow of air through an outflow valve is determined by the degree of valve opening. This valve is ordinarily controlled by an automatic system which can be set by the flight crewmembers. A few simple minor adjustments are required on the average flight, but most of the time automatic controls need only to be monitored. In the event of a malfunction of the automatic controls, manual controls are also provided. A schematic of a basic pressurization system is shown in figure 14-3.

The degree of pressurization and, therefore, the operating altitude of the aircraft are limited by several critical design factors. Primarily the fuselage is designed to withstand a particular maximum cabin differential pressure. Cabin differential pres-

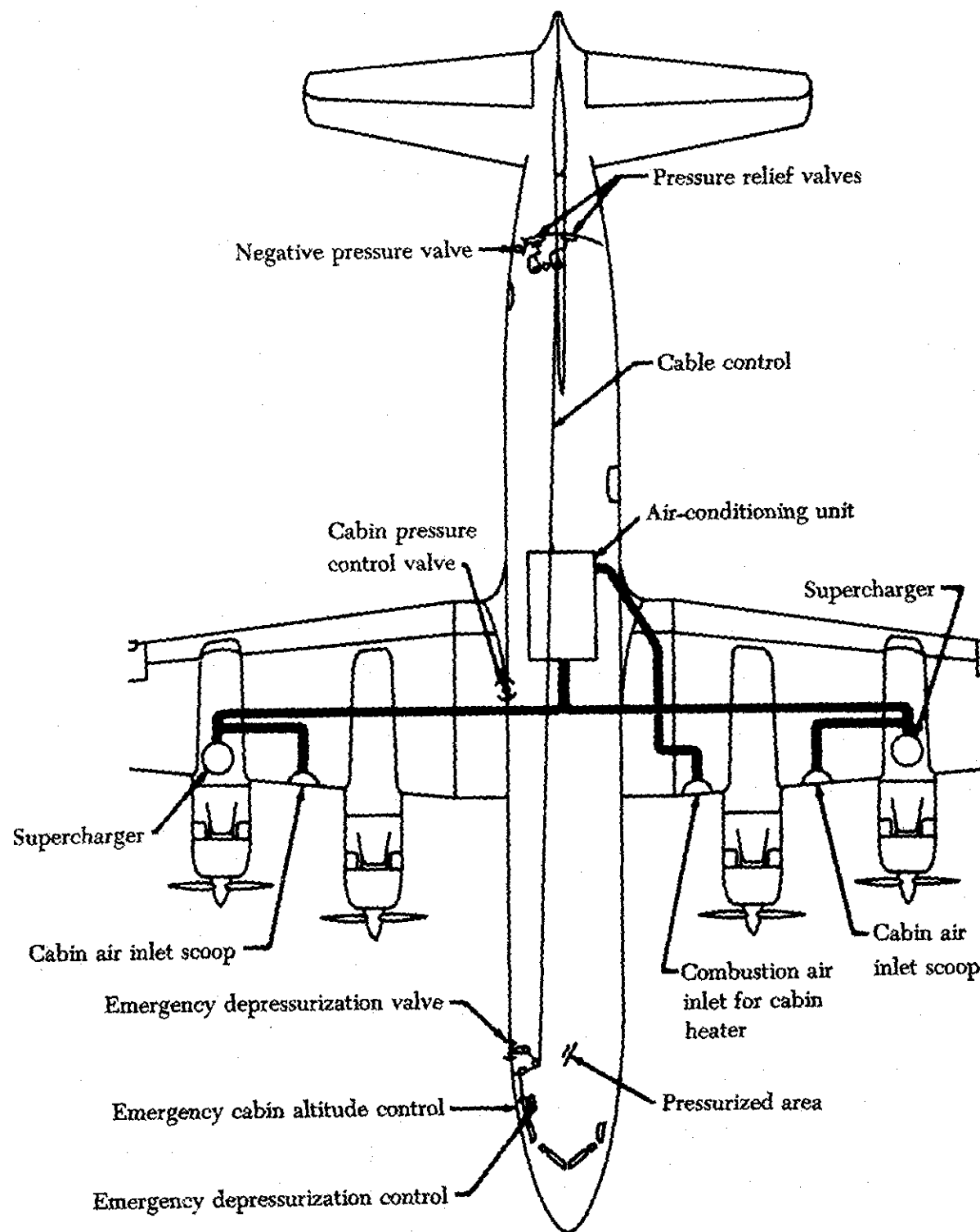


FIGURE 14-3. Basic pressurization system.

sure is the ratio between inside and outside air pressures and is a measure of the internal stress on the fuselage skin. If the differential pressure be-

comes too great, structural damage to the fuselage may occur. In addition, pressurization is limited by the capacity of the superchargers to maintain a

constant volume of airflow to the fuselage. As altitude is increased, the pressure of the air entering the supercharger becomes less; consequently, the superchargers have to work harder to accomplish their part of the job. Eventually at some high altitude the superchargers will reach their designed limit of speed, power absorbed, or some other operating factor. The aircraft will normally not be flown higher than these limits allow.

Pressurization Problems

There are many complex technical problems associated with pressurized aircraft. Perhaps the most difficult problems are in the design, manufacturing, and selection of structural materials which will withstand the great differential in pressure that exists between the inside and outside of a pressurized aircraft when flying at high altitudes. If the weight of the aircraft structure were of no concern, it would be a relatively simple matter to construct a fuselage which could withstand tremendous pressures.

It is necessary to construct a fuselage capable of containing air under pressure, yet be light enough to allow profitable loading. As a general rule pressurized aircraft are built to provide a cabin pressure altitude of not more than 8,000 ft. at maximum operating altitude. If an aircraft is designed for operation at altitudes over 25,000 ft., it must be capable of maintaining a cabin pressure altitude of 15,000 ft., in the event of any reasonably likely failure.

The atmospheric pressure at 8,000 ft. is approximately 10.92 p.s.i., and at 40,000 ft. it is nearly 2.72 p.s.i. If a cabin altitude of 8,000 ft. is maintained in an aircraft flying at 40,000 ft. the differential pressure which the structure will have to withstand is 8.20 p.s.i. (10.92 p.s.i. minus 2.72 p.s.i.). If the pressurized area of this aircraft contains 10,000 sq. in., the structure will be subjected to a bursting force of 82,000 lbs., or approximately 41 tons. In addition to designing the fuselage to withstand this force, a safety factor of 1.33 must be added. The pressurized portion of the fuselage will have to be constructed to have an ultimate strength of 109,060 lbs. (82,000 times 1.33), or 54.5 tons.

From the foregoing example it is not difficult to grasp an idea of the difficulties encountered in designing and building a fuselage structure which will be light enough and strong enough at the same time.

AIR CONDITIONING AND PRESSURIZATION SYSTEMS

The cabin air conditioning and pressurization system supplies conditioned air for heating and cooling the cockpit and cabin spaces. This air also provides pressurization to maintain a safe, comfortable cabin environment. In addition to cabin air conditioning, some aircraft equipment and equipment compartments require air conditioning to prevent heat buildup and consequent damage to the equipment.

Some of the air conditioning systems installed in modern aircraft utilize air turbine refrigerating units to supply cooled air. These are called air cycle systems. Other model aircraft utilize a compressed gas cooling system. The refrigerating unit is a freon type, quite similar in operation to a common household refrigerator. Systems utilizing this refrigeration principle are called vapor cycle systems.

Terms and Definitions

The system which maintains cabin air temperatures is the air conditioning system. The sources of heat which make cabin air conditioning necessary are: (1) Ram-air temperature, (2) engine heat, (3) solar heat, (4) electrical heat, and (4) body heat.

It is necessary to become familiar with some terms and definitions to understand the operating principles of pressurization and air conditioning systems. These are:

- (1) *Absolute pressure.* Pressure measured along a scale which has zero value at a complete vacuum.
- (2) *Absolute temperature.* Temperature measured along a scale which has zero value at that point where there is no molecular motion (-273.1°C. or -459.6°F.).
- (3) *Adiabatic.* A word meaning no transfer of heat. The adiabatic process is one in which no heat is transferred between the working substance and any outside source.
- (4) *Aircraft altitude.* The actual height above sea level at which an aircraft is flying.
- (5) *Ambient temperature.* The temperature in the area immediately surrounding the object under discussion.
- (6) *Ambient pressure.* The pressure in the area immediately surrounding the object under discussion.
- (7) *Standard barometric pressure.* The weight of gases in the atmosphere sufficient to

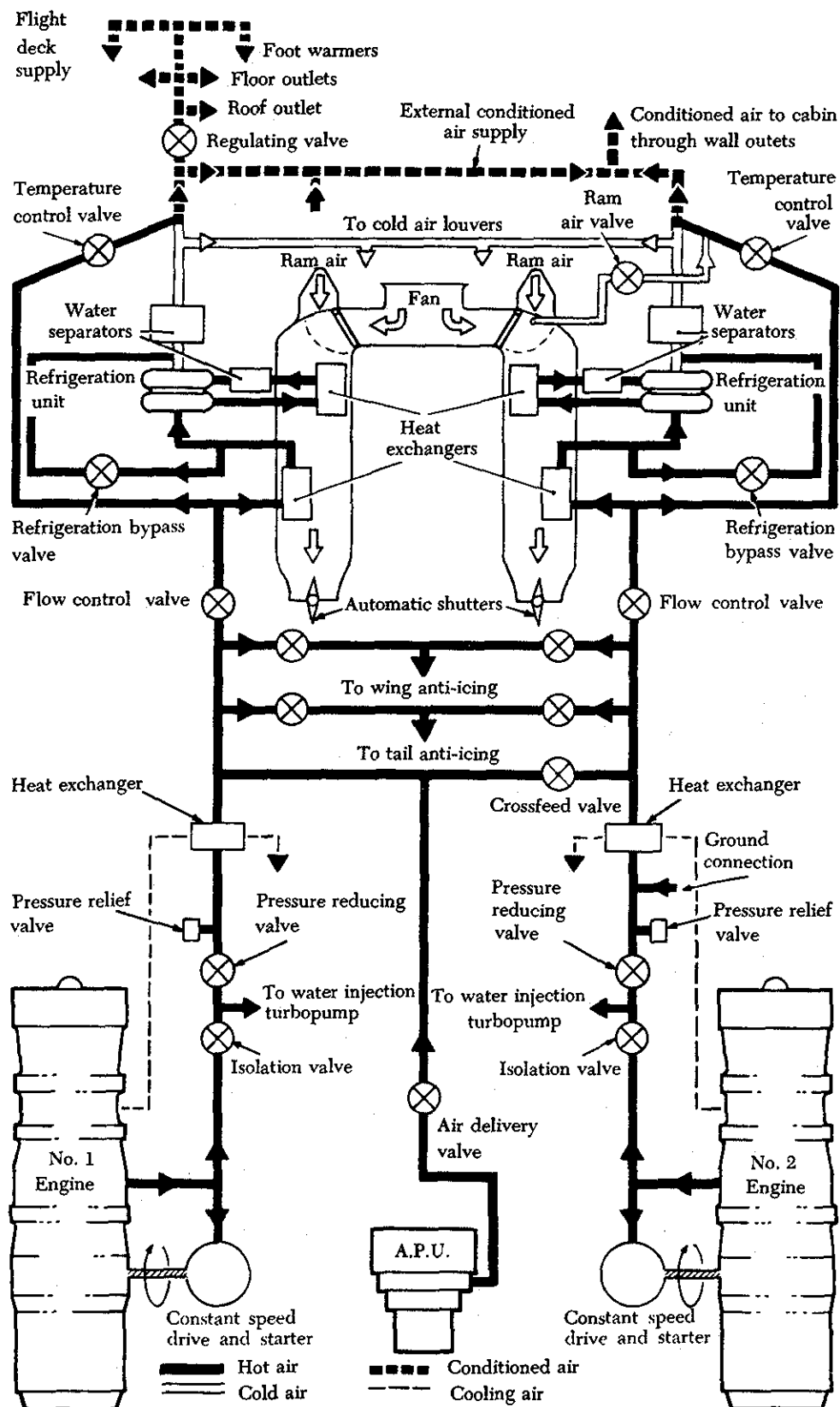


FIGURE 14-4. Typical pressurization and air conditioning system.

hold up a column of mercury 760 millimeters high (approximately 30 in.) at sea level (14.7 p.s.i.). This pressure decreases with altitude.

- (8) *Cabin altitude.* Used to express cabin pressure in terms of equivalent altitude above sea level.
- (9) *Differential pressure.* The difference in pressure between the pressure acting on one side of a wall and the pressure acting on the other side of the wall. In aircraft air conditioning and pressurizing systems, it is the difference between cabin pressure and atmospheric pressure.
- (10) *Gage pressure.* A measure of the pressure in a vessel, container, or line, as compared to ambient pressure.
- (11) *Ram-air temperature rise.* The increase in temperature created by the ram compression on the surface of an aircraft traveling at a high rate of speed through the atmosphere. The rate of increase is proportional to the square of the speed of the object.
- (12) *Temperature scales.*
 - (a) *Centigrade.* A scale on which 0° C. represents the freezing point of water, and 100° C. is equivalent to the boiling point of water at sea level.
 - (b) *Fahrenheit.* A scale on which 32° F. represents the freezing point of water, and 212° F. is equivalent to the boiling point of water at sea level.

BASIC REQUIREMENTS

Five basic requirements for the successful functioning of a cabin pressurization and air conditioning system are:

- (1) A source of compressed air for pressurization and ventilation. Cabin pressurization sources can be either engine-driven compressors, independent cabin superchargers, or air bled directly from the engine.
- (2) A means of controlling cabin pressure by regulating the outflow of air from the cabin. This is accomplished by a cabin pressure regulator and an outflow valve.
- (3) A method of limiting the maximum pressure differential to which the cabin pressurized area will be subjected. Pressure

relief valves, negative (vacuum) relief valves, and dump valves are used to accomplish this.

- (4) A means of regulating (in most cases cooling) the temperature of the air being distributed to the pressurized section of the airplane. This is accomplished by the refrigeration system, heat exchangers, control valves, electrical heating elements, and a cabin temperature control system.
- (5) The sections of the aircraft which are to be pressurized must be sealed to reduce inadvertent leakage of air to a minimum. This area must also be capable of safely withstanding the maximum pressure differential between cabin and atmosphere to which it will be subjected.

Designing the cabin to withstand the pressure differential and hold leakage of air within the limits of the pressurization system is primarily an air-frame engineering and manufacturing problem.

In addition to the components just discussed, various valves, controls, and allied units are necessary to complete a cabin pressurizing and air conditioning system. When auxiliary systems such as windshield rain-clearing devices, pressurized fuel tanks, and pressurized hydraulic tanks are required, additional shutoff valves and control units are necessary.

Figure 14-4 shows a schematic diagram of a pressurization and air conditioning system. The exact details of this system are peculiar to only one model of aircraft, but the general concept is similar to that found in the majority of aircraft.

SOURCES OF CABIN PRESSURE

Reciprocating engine internal superchargers provide the simplest means of cabin pressurization. This is accomplished by ducting air from a manifold which supplies compressed air from a supercharger to the pistons. This arrangement can be used only when the engine carburetor is downstream of the supercharger. When the carburetor is upstream of the supercharger, as is often the case, this method cannot be used since the compressed air contains fuel. Air for cabin pressurization can also be ducted from a turbocharger used with a reciprocating engine.

There are several disadvantages in using these two methods. The cabin air becomes contaminated with fumes from lubricating oil, exhaust gases, and fuel. Also, cabin pressurization at high altitude be-

comes impossible as the discharge pressure of the supercharger decreases to nearly ambient. A third disadvantage is the decrease in engine performance near its design ceiling due to the air loss for cabin pressurization.

With gas turbine engines the cabin can be pressurized by bleeding air from the engine compressor. Usually the air bled from an engine compressor is sufficiently free from contamination and can be used safely for cabin pressurization. Even so, there are several disadvantages when using bleed air from turbine engine compressors. Among these disadvantages are: (1) The possibility of contamination of the air from lubricants or fuel in the event of leakage, and (2) dependence of the air supply on the engine performance.

Because of the many disadvantages associated with the pressurizing sources previously described, independent cabin compressors have been designed. These compressors can be engine driven through accessory drive gearing or can be powered by bleed air from a turbine engine compressor.

Generally, the compressors can be separated into two groups, (1) positive-displacement compressors and (2) centrifugal compressors.

Positive-Displacement Cabin Compressors (Superchargers)

Included in this group are reciprocating compressors, vane-type compressors, and Roots blowers. The first two are not very suitable for aircraft cabin pressurization because of the large quantity of oil present in the air delivered to the cabin.

The action of a Roots-type blower (figure 14-5) is based on the intake of a predetermined volume of air, which is subsequently compressed and delivered to the cabin duct.

The rotors are mounted in an airtight casing on two parallel shafts. The lobes do not touch each other or the casing, and both rotors turn at the same speed. Air enters the spaces between the lobes, is compressed, and is delivered to the cabin air duct.

A cutaway view of a cabin supercharger is shown in figure 14-6. The supercharger housing is usually finned on the external surface to increase its cooling area. The cooling effect is sometimes further increased by shrouding the supercharger housing and passing a stream of air through it. Air cooling is also used to reduce the temperature of internal parts. The cooling air is ducted through drilled

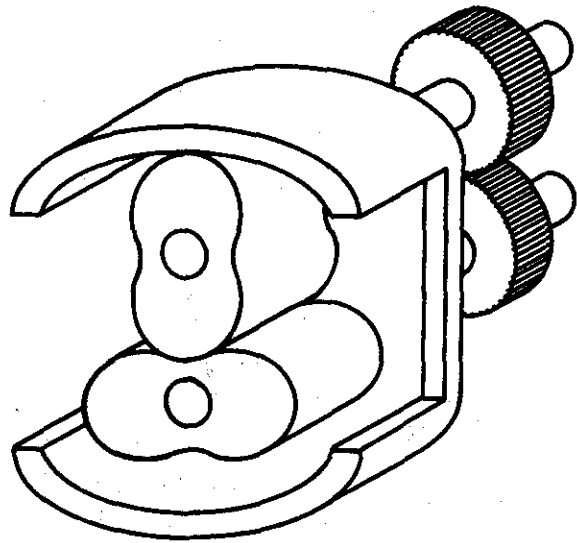


FIGURE 14-5. Schematic Roots-type cabin compressor.

passageways into the rotor cavities and is expelled at the inlet side of the supercharger cover.

To achieve an oil-free delivery of air, the supercharger bearings are contained in separate chambers. The rotor shafts can be fitted with seals made of oil-resistant rubber which prevents any lubricant from entering the compressor casing. The use of labyrinth seals permits a small amount of air leakage to ambient. Any drops of oil which may have passed the rubber seal are thus blown back.

Positive displacement compressors emit a shrill noise during their operation, because of the air pulsations caused by the rotors. Silencers are used with this type compressor to reduce the noise level.

Centrifugal Cabin Compressors

The operating principle of a centrifugal compressor is based on increasing the kinetic energy of the air passing through the impeller. With compressor impeller rotation, the induced air is not only accelerated, but it is also compressed because of the action of centrifugal force. The kinetic energy in the air is then converted into pressure in the diffuser. There are two basic types of diffusers: (1) Vaneless, where the air enters the diffuser space directly on leaving the impeller, and (2) those having guide vanes. A schematic of a centrifugal cabin compressor is shown in figure 14-7.

The cabin supercharger shown in figure 14-8 is essentially an air pump. It incorporates a centrifugal impeller similar to the supercharger in the induction system of a reciprocating engine. Outside

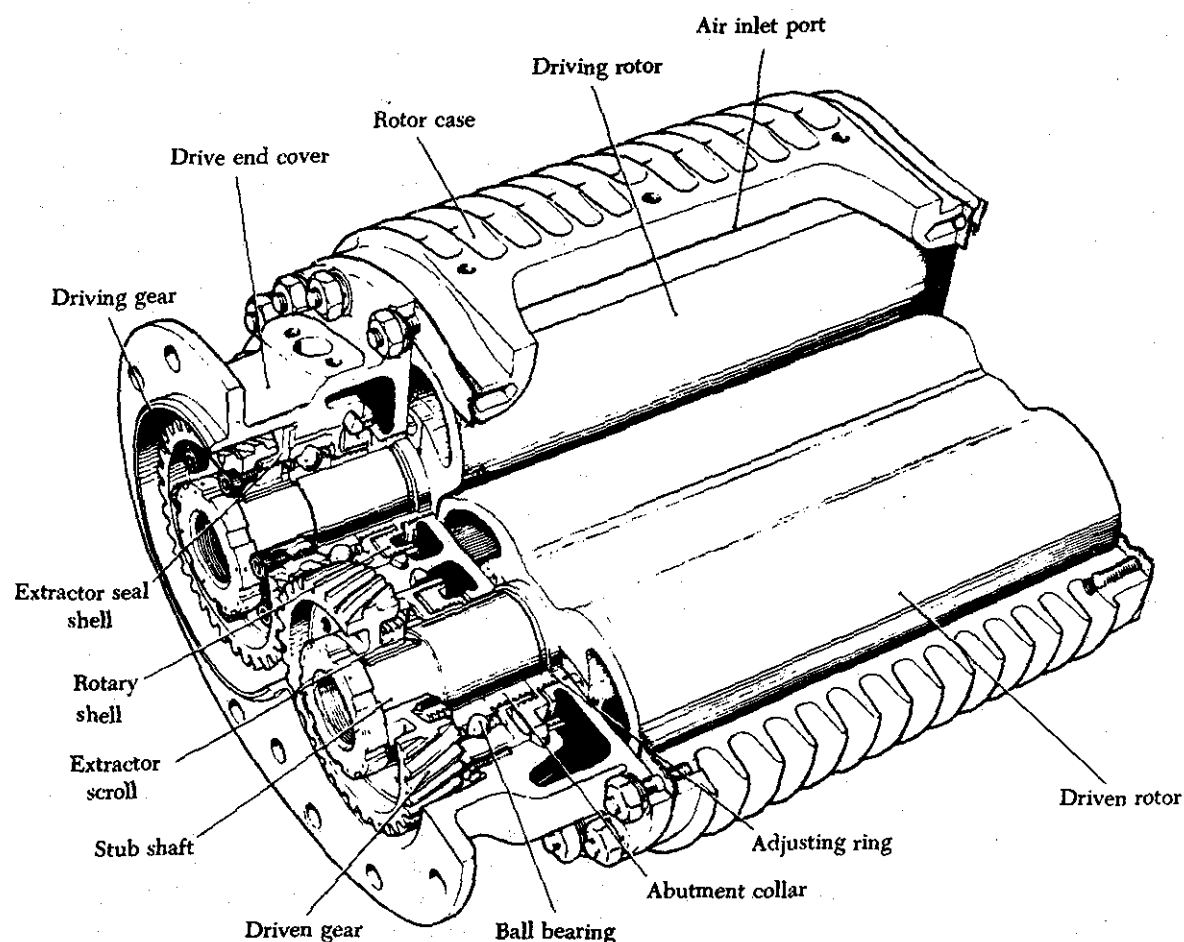


FIGURE 14-6. Cutaway view of a Roots-type cabin supercharger.

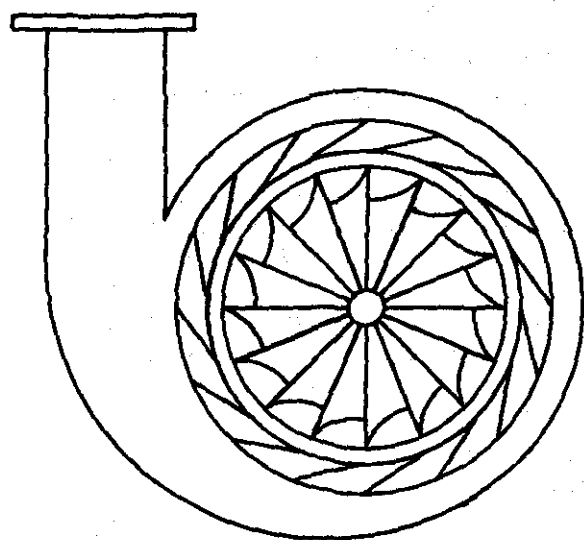


FIGURE 14-7. Centrifugal cabin compressor.

air at atmospheric pressure is admitted to the supercharger by suitable scoops and ducts. This air is then compressed by the high-speed impeller and delivered to the fuselage. The superchargers are usually driven by the engine through appropriate gearing; however, turbojet aircraft utilize superchargers (turbocompressors) which are pneumatically driven.

Engine-driven cabin superchargers are generally mounted in the engine nacelle. The supercharger is either splined directly to the engine accessory drive or is connected to an accessory drive by a suitable drive shaft. A mechanical disengaging mechanism is usually incorporated in the drive system to permit disconnecting the supercharger if it malfunctions. The disengaging mechanism can be operated from the flight deck by the crew. In most aircraft it is not possible or permissible to re-engage the supercharger in flight once it has been disconnected.

Engine-driven superchargers used on reciprocating

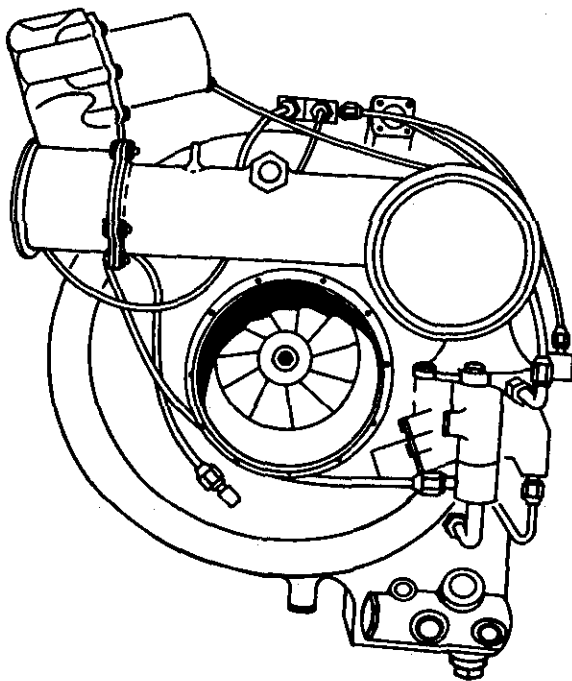


FIGURE 14-8. Pictorial view of a centrifugal cabin supercharger.

ing engine aircraft require a variable-ratio drive mechanism. The gear ratio of these superchargers is automatically adjusted to compensate for changes of engine r.p.m. or outside atmospheric pressure. Normally, the gear ratio is eight to 10 times engine speed when operating under cruising conditions. The drive ratio is at a maximum when operating at high altitude with low engine r.p.m.

Turbocompressors used on turbojet aircraft may be located in the engine nacelles or in the fuselage. There may be as many as four turbocompressors in an aircraft. Turbocompressors consist of a turbine rotated by air pressure which in turn rotates an impeller. The compressed air supply used to operate the turbocompressor is taken from the aircraft's pneumatic system. Speed of the turbocompressor is controlled by varying the supply of compressed air to its turbine.

Cabin superchargers of all types contain their own lubrication system. The lubricant used may be the same type oil used for the engine, or it may be a special oil similar to hydraulic fluid. Supercharger bearings and gears are lubricated by pressure and spray. Oil pressure is also used to operate the control system for the supercharger. The typical lubrication system incorporates a pump, relief valve,

sump, cooling system, and sometimes a separate oil tank.

High impeller speed is an important limitation in all superchargers. When the tip speed of the impeller approaches the speed of sound, the impeller rapidly loses its efficiency as an air pump. An equally important limitation involves the back pressure created in the outlet air ducts. If the back pressure is excessive, the impeller may stall or surge.

Supercharger Control

The function of the supercharger control system is to maintain a fairly constant volume of air output from the supercharger. This is accomplished in the system used on reciprocating engine aircraft by varying the drive ratio of the supercharger. The drive ratio between the supercharger impeller and the engine is varied to compensate for changes in engine r.p.m. or atmospheric pressure. This is achieved by an automatic mechanism which samples the airflow output of the supercharger and, through a variable-speed drive gearbox, adjusts the impeller speed whenever the airflow output varies from a preset value.

The amount of f.hp. (friction horsepower) taken from the engine to drive the supercharger is dependent upon the drive ratio. Losses are lowest during low-ratio operation when the energy required to rotate the impeller is at a minimum. Losses are approximately 75 f.hp. in high ratio and 25 f.hp. in low ratio. This loss is indicated at high altitudes, where, the engines which drive the cabin superchargers may require 3 or 4 in. Hg additional manifold pressure to produce the same b.hp. (brake horsepower) as that of other engines.

The speed of the supercharger impeller is therefore adjusted by the control system to maintain a constant mass airflow output. If variables such as altitude tend to increase or decrease the output, the control mechanism causes a correction of the drive ratio. Changes of drive ratio are furthermore dampened by various system refinements to prevent rapid acceleration or deceleration which may result in uncomfortable surges of pressurization.

Serious consequences may occur if the impeller speed becomes higher than its designed maximum. To protect the supercharger against such an occurrence, the typical system has an overspeed governor. This unit is similar to a propeller flyweight governor. The overspeed governor actuates a valve to position the control mechanism to the low-ratio po-

sition. It works automatically to reduce impeller r.p.m. when an overspeed occurs.

Some installations also have an electrically operated valve which positions the control mechanism to the low-speed position. This minimum speed valve may be operated manually from the flight deck or automatically by a landing gear strut switch. It is used primarily to reduce supercharger drive ratio when pressurization is not being used or when emergencies occur.

SUPERCHARGER INSTRUMENTS

The principal instrument associated with the supercharger is an airflow gage. This gage usually measures the differential air pressure between the input and the output of the supercharger. In some cases there are two needles on the gage to indicate input and output pressures on the same scale. The airflow (or input and output pressure) gage indicates the proper operation of the supercharger. High readings, low readings, or fluctuating readings indicate various types of malfunctions.

Oil pressure and oil temperature indications are also made available by suitable instruments on the flight deck. In some cases warning lights may be used instead of, or in addition to, the actual gages.

Engine-driven cabin compressors are used on turboprop aircraft. These compressors do not have a variable-speed drive because the turboprop engine operates at a relatively constant speed. The output of this type compressor is controlled by automatically varying the inlet airflow through an airflow-sensing mechanism and a suitable inlet valve which maintains a constant compressor airflow output.

Ordinarily a surge and dump valve is used at the outlet of the compressor. In some systems this is the only type of control employed for the compressor. The surge and dump valve prevents surging of the compressor by partially reducing output pressure when system demands are heavy. The valve can also completely dump output pressure when the engine-driven compressor output is not needed. This valve can be operated from the flight deck and is also operated by various automatic control systems. When the surge and dump valve is opened, the engine-driven cabin compressor output is dumped overboard through suitable ducts.

Instruments used in conjunction with the engine-driven compressor are similar to those used with the variable-speed supercharger. An inlet and discharge pressure gage measures compressor pressures. Com-

pressor high oil temperature and low oil pressure are usually indicated by warning lights.

Turbocompressors used on turbojet aircraft are similar in operation to the exhaust-driven turbochargers used with some reciprocating engines. Power derived from the aircraft's pneumatic system is used to drive the turbine of the unit. Since the turbocompressors do not rely upon direct engine drive shafts, they can be placed either in the engine nacelles or in the fuselage. Ordinarily multiple turbocompressor units are used to provide the high airflow needed by the large turbojet aircraft. The output of the turbocompressor units is usually controlled by varying the pneumatic supply to the turbine.

The pneumatic air supply is obtained from the compressor section of the turbojet engine. This air supply is regulated to a constant pressure of approximately 45 p.s.i. to 75 p.s.i. Pneumatic system air pressure is also used to operate anti-icing and other aircraft systems; therefore, various shutoff valves and check valves are used to isolate inoperative units of the turbocompressor system.

The turbocompressor output is controlled automatically by an airflow control valve and servo-operated inlet vanes. The inlet vanes control the pneumatic system air supply to the turbocompressor turbine. The vanes open or close according to the air pressure signal sensed at the airflow control valve, and turbocompressor speed is increased or decreased to maintain a relatively constant output air volume. Turbocompressor speed will therefore increase with altitude.

The principal turbocompressor control is a simple "on/off" valve. This valve is located in the pneumatic air duct. In the "off" position it completely closes off the pneumatic supply to the turbine. Various special circuits may also actuate this shutoff valve when operation of the turbocompressor is not desired.

Most turbocompressor units incorporate an overspeed control. A typical overspeed control unit is a simple flyweight governor which causes the turbocompressor to completely shut down when a certain limiting r.p.m. is reached. Usually the pneumatic duct shutoff valve is closed by the overspeed control. The turbocompressor system also uses a surge and dump valve similar to that used for engine-driven compressors.

The flight deck instruments are the same as those used on engine-driven systems with the addition of

a tachometer which measures turbocompressor speed. Turbocompressor speed on a typical aircraft varies from approximately 20,000 r.p.m. at sea level to 50,000 r.p.m. at 40,000 ft. The overspeed control may be set at about 55,000 r.p.m.

PRESSURIZATION VALVES

The principal control of the pressurization system is the outflow valve. This valve is placed in a pressurized portion of the fuselage, usually underneath the lower compartments. The purpose of the valve is to vent cabin air overboard through suitable openings in the wing fillet or the fuselage skin. Small aircraft use one outflow valve; large aircraft may use as many as three valves which work in unison to provide the required volume outflow.

One type of outflow valve is a simple butterfly which is opened or closed by an electric motor. The motor receives amplified electrical signals from the pressurization controller to vary the valve position required for pressurized flight.

Some aircraft use a pneumatic outflow valve (figure 14-9). This valve receives signals from the pressurization controller in the form of controlled air pressures. The air pressures which operate the valve are obtained from the high pressure inside the cabin, with assistance from the pneumatic system pressure in turbine-powered aircraft.

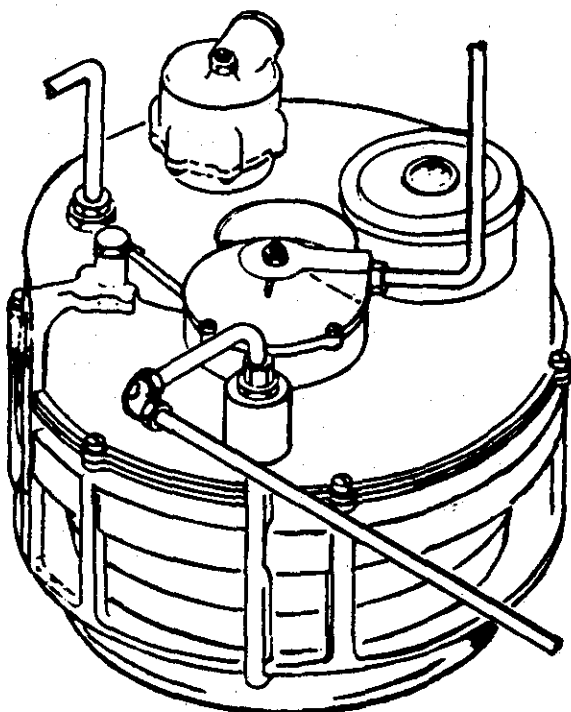


FIGURE 14-9. Typical pneumatic outflow valve.

In many aircraft, the outflow valve(s) will be held fully open on the ground by a landing gear operated switch. During flight, as altitude is gained, the valve(s) close(s) gradually to make a greater restriction to the outflow of cabin air. The cabin rate of climb or descent is determined by the rate of closing or opening of the outflow valve(s). During cruising flight the cabin altitude is directly related to the degree of outflow valve opening.

In addition to the controllable outflow valve(s), an automatic cabin pressure relief valve is used on all pressurized aircraft. This valve may actually be built into the outflow valve or may be an entirely separate unit. The pressure relief valve automatically opens when the cabin differential pressure reaches a preset value.

All pressurized aircraft require some form of a negative pressure relief valve. This valve may also be incorporated into the outflow valve or may be an individual unit. A common form of negative pressure relief valve is a simple hinged flap on the rear wall (pressure dome) of the cabin. This valve opens when outside air pressure is greater than cabin pressure. During pressurized flight the internal cabin pressure holds the flap closed. The negative pressure relief valve prevents accidentally obtaining a cabin altitude which is higher than the aircraft altitude.

The outflow of air from the cabin can also be accomplished through a manually operated valve. This valve may be called a safety relief valve, a manual depressurization valve, or some other similar term. The manual valve is used to control pressurization when all other means of control fail. It is primarily intended to permit rapid depressurization during fires or emergency descent.

Pressurization Controls

The pressurization controller (figure 14-10) is the source of control signals for the pressurization system. The controller provides adjustments to obtain the desired type of pressurized condition. Most operators specify standard operating procedures for the controller which have proven best for their particular type of operation.

The controller looks very much like an altimeter which has several added adjustment knobs. The dial is graduated in cabin altitude increments up to approximately 10,000 ft. Usually there is one pointer which can be adjusted to the desired cabin altitude by the cabin altitude set knob. In some cases there is another pointer or a rotating scale which also

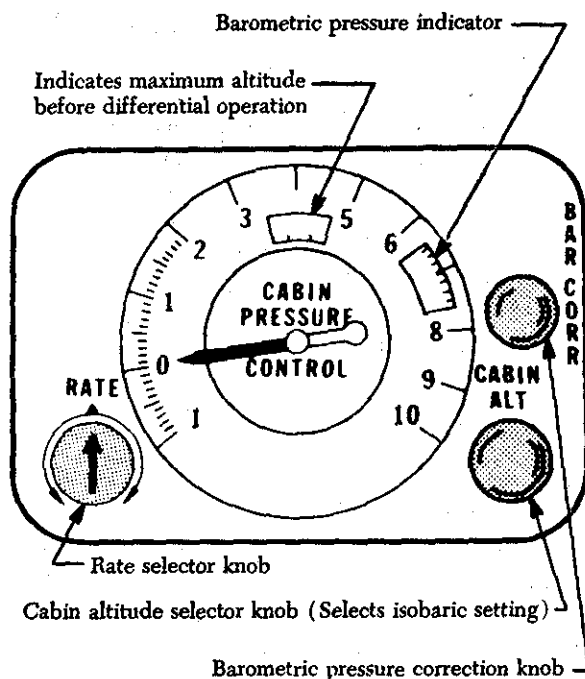


FIGURE 14-10. Pressurization controller.

indicates the corresponding aircraft pressure altitude. A separate knob adjusts the controller to the existing altimeter setting (or sea level barometric pressure). The barometric setting selected is indicated on a separate dial segment. The third knob on the controller adjusts the cabin rate of altitude change. This adjustment can be made on a separate control in some installations.

When the controller knobs are set, adjustments are made on either an electric or a pneumatic signaling device inside the controller. The settings are compared to the existing cabin pressure by an aneroid or evacuated bellows. If the cabin altitude does not correspond to that which is set by the knobs, the bellows causes the appropriate signal to go to the outflow valve. When the bellows determines that the cabin altitude has reached that which has been set, the signals to the outflow valve are stopped. As long as other factors do not change, the outflow valve is held at the setting to maintain desired cabin pressure. The controller can sense any change, such as variance of aircraft altitude or loss of one supercharger, and re-adjust the outflow valve as necessary.

The rate control determines how fast the controller sends signals to the outflow valve. In some controllers the rate signal is partially automatic. The

barometric setting compensates the controller for the normal errors in altimetry which are encountered on most flights. This setting improves the accuracy of the controller and, as an example, protects the cabin from being partially pressurized while a landing is being made.

The signals which originate in the controller are very weak. This is because it is a delicate instrument and cannot handle high electric voltages or pneumatic forces. These weak signals are amplified, either electrically or pneumatically, to operate the outflow valve.

Several instruments are used in conjunction with the pressurization controller. The cabin differential pressure gage indicates the difference between inside and outside pressure. This gage should be monitored to assure that the cabin is not approaching the maximum allowable differential pressure. A cabin altimeter is also provided as a check on the performance of the system. In some cases, these two instruments are combined into one. A third instrument indicates the cabin rate of climb or descent. A cabin rate of climb instrument and a cabin altimeter are illustrated in figure 14-11.

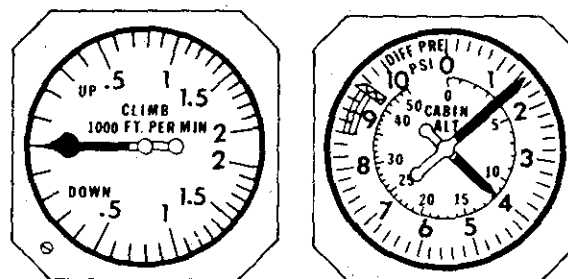


FIGURE 14-11. Instruments for pressurization control.

CABIN PRESSURE CONTROL SYSTEM

The cabin pressure control system is designed to provide cabin pressure regulation, pressure relief, vacuum relief, and the means for selecting the desired cabin altitude in the isobaric and differential range. In addition, dumping of the cabin pressure is a function of the pressure control system. A cabin pressure regulator, an outflow valve, and a safety valve are used to accomplish these functions.

Cabin Pressure Regulator

The cabin pressure regulator controls cabin pressure to a selected value in the isobaric range and limits cabin pressure to a preset differential value in the differential range. The isobaric range maintains

the cabin at constant-pressure altitude during flight at various levels. It is used until the aircraft reaches the altitude at which the difference between the pressure inside and outside the cabin is equal to the highest differential pressure for which the fuselage structure is designed. Differential control is used to prevent the maximum differential pressure, for which the fuselage was designed, from being exceeded. This differential pressure is determined by the structural strength of the cabin and often by the relationship of the cabin size to the probable areas of rupture, such as window areas and doors.

The cabin pressure regulator is designed to control cabin pressure by regulating the position of the outflow valve. The regulator usually provides either fully automatic or manual control of pressure within the aircraft. Normal operation is automatic, requiring only the selection of the desired cabin altitude and rate-of-change of cabin pressure.

The cabin pressure regulator may be constructed integral with the outflow valve or may be mounted remote from the outflow valve and connected to it by external plumbing. In either instance the principle of operation is similar.

The regulator illustrated in figure 14-12 is integral with the outflow valve. This regulator is a differential pressure type, normally closed, pneumatically controlled and operated. This type regulator consists of two principal sections: (1) The head and reference chamber section, and (2) the outflow valve and diaphragm section.

The outflow valve and diaphragm section contains a base, a spring-loaded outflow valve, an actuator diaphragm, a balance diaphragm, and a baffle plate. The baffle plate is attached to the end of a pilot which extends from the center of the cover assembly. The outflow valve rides on the pilot

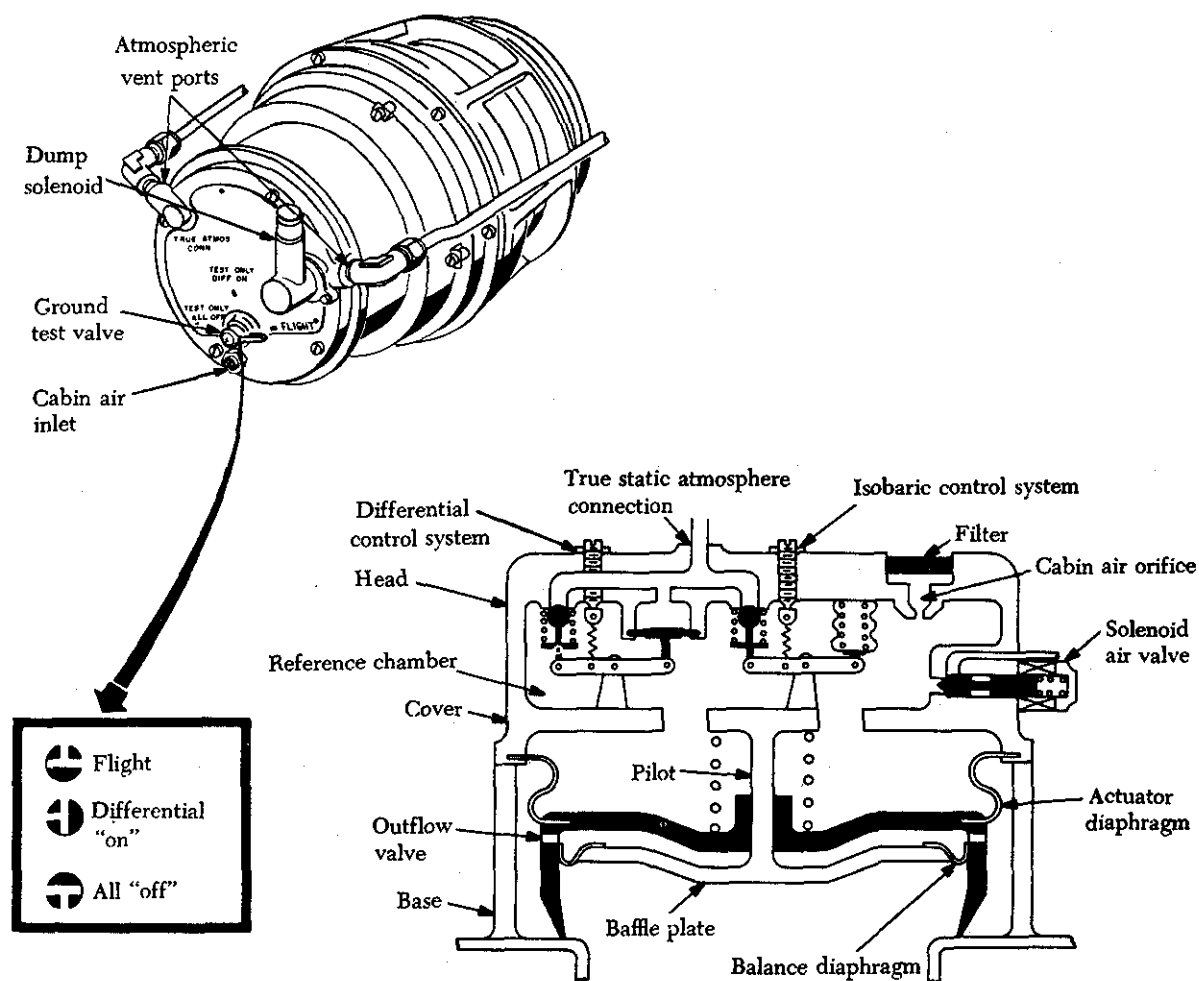


FIGURE 14-12. Cabin air pressure regulator.

between the cover and the baffle plate and is spring loaded to a closed position against the base.

The balance diaphragm extends outward from the baffle plate to the outflow valve, creating a pneumatic chamber between the fixed baffle plate and the inner face of the outflow valve. Cabin air flows into this chamber through holes in the side of the outflow valve to exert a force against the inner face, opposing spring tension, to open the valve. The actuator diaphragm extends outward from the outflow valve to the cover assembly, creating a pneumatic chamber between the cover and the outer face of the outflow valve. Air from the head and reference chamber section flows through holes in the cover, filling this chamber and exerting a force against the outflow valve's outer face to aid the spring tension in holding the valve closed. The position of the outflow valve controls the flow of cabin air to atmosphere for cabin pressure control. The action of components in the head and reference chamber section controls the movements of the outflow valve by varying the pressure of reference chamber air being exerted against the outer face of the valve.

The head and reference chamber section includes an isobaric control system, a differential control system, a filter, a ground test valve, a true static atmosphere connection, and a solenoid air valve. The area inside the head is called the reference chamber.

The isobaric control system incorporates an evacuated bellows, a rocker arm, a follower spring, and an isobaric metering valve. One end of the rocker arm is connected to the head by the evacuated bellows. The other end of the arm positions the metering valve to a normally closed position against a passage in the head. A follower spring between the metering valve seat and a retainer on the valve causes the valve to move away from its seat as the rocker arm permits.

Whenever the reference chamber air pressure is great enough to compress the bellows the rocker arm pivots about its fulcrum. This allows the metering valve to move from its seat an amount proportionate to the amount of compression in the bellows. When the metering valve is open, reference chamber air flows to atmosphere through the true static atmosphere connection.

The differential control system incorporates a diaphragm, a rocker arm, a metering valve, and a follower spring. One end of the rocker arm is at-

tached to the head by the diaphragm. The diaphragm forms a pressure-sensitive face between the reference chamber and a small chamber in the head. This small chamber is opened to atmosphere through a passage to the true static atmosphere connection. Atmospheric pressure acts on one side of the diaphragm and reference chamber pressure acts on the other. The opposite end of the rocker arm positions the metering valve to a normally closed position against a passage in the head. A follower spring between the metering valve seat and a retainer on the valve causes the valve to move away from its seat as the rocker arm permits.

When reference chamber pressure exceeds atmospheric pressure sufficiently to move the diaphragm, the metering valve is allowed to move from its seat an amount proportionate to the movement of the diaphragm. When the metering valve is open, reference chamber air flows to atmosphere through the true static atmosphere connection.

By regulating reference chamber air pressure, the isobaric and differential control systems control the actions of the outflow valve to provide for three modes of operation called unpressurized, isobaric, and differential.

During unpressurized operation, figure 14-13, reference chamber pressure is sufficient to compress the isobaric bellows and open the metering valve. Cabin air entering the reference chamber through the cabin air orifice flows to the atmosphere through the isobaric metering valve. Since the cabin air orifice is smaller than the orifice formed by the metering valve, reference chamber pressure is maintained at a value slightly less than cabin pressure. As pressure increases in the cabin, the differential pressure between the outflow valve inner and outer face increases. This unseats the outflow valve and allows cabin air to flow to the atmosphere.

As the isobaric range (figure 14-14) is approached reference chamber pressure, which has been decreasing at the same rate as atmospheric pressure, will have decreased enough to allow the isobaric bellows to expand and move the metering valve toward its seat. As a result, the flow of reference chamber air through the metering valve is reduced, preventing further decrease in reference pressure. In response to slight changes in reference chamber pressure, the isobaric control system modulates to maintain a substantially constant reference pressure in the chamber throughout the isobaric range of operation. Responding to the differential

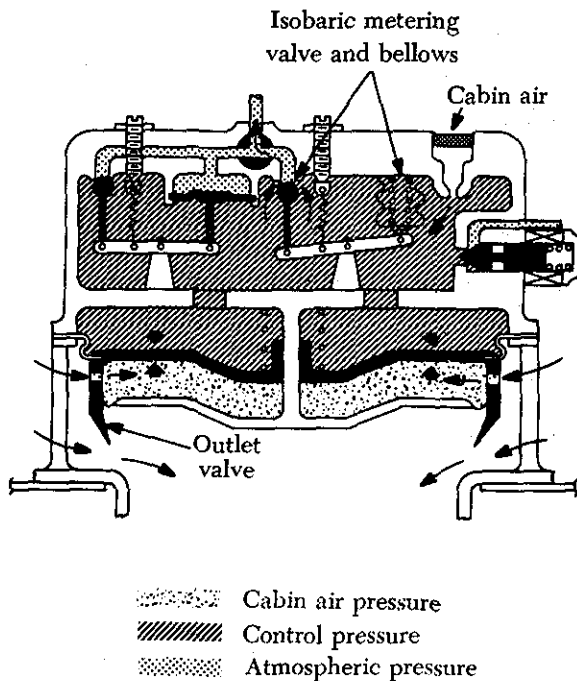


FIGURE 14-13. Cabin air pressure regulator in the unpressurized mode.

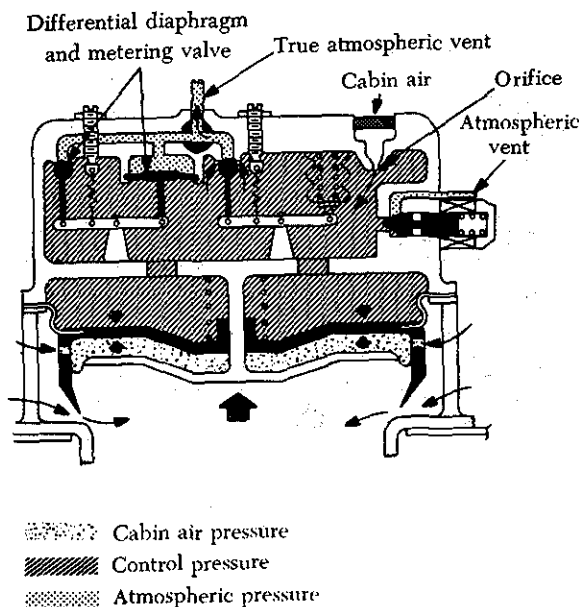


FIGURE 14-14. Cabin air pressure regulator in the isobaric range.

between the constant reference chamber pressure and the variable cabin pressure, the outflow valve opens or closes, metering air from the cabin, as required, to maintain a constant cabin pressure.

As the differential range is approached, the pressure differential between the constant reference pressure and the decreasing atmospheric pressure becomes sufficient to move the diaphragm and open the differential metering valve. As a result, reference chamber air flows to atmosphere through the differential metering valve, reducing the reference pressure. Responding to the decreased reference pressure, the isobaric bellows expands and closes the isobaric metering valve completely. Reference chamber pressure is now controlled, through the differential metering valve, by atmospheric pressure being reflected against the differential diaphragm. As atmospheric pressure decreases, the metering valve opens more and allows reference pressure to decrease proportionately. Responding to the pressure differential between cabin and reference pressures, the outflow valve opens or closes as required to meter air from the cabin and maintain a predetermined differential pressure value.

In addition to the automatic control features just described, the regulator incorporates a ground test valve and a solenoid air valve, both of which are located in the head and reference chamber section. The solenoid air valve is an electrically activated valve spring-loaded to a normally closed position against a passage through the head that opens the reference chamber to atmosphere. When the cockpit pressure switch is positioned to "ram" the regulator solenoid opens, causing the regulator to dump cabin air to the atmosphere.

The ground test valve (see figure 14-12) is a three-position, manually operated control that allows for performance checks of the regulator and cabin pressurization system. In the "test only—all off" position the valve renders the regulator completely inoperative. In the "test only—differential on" position, the valve renders the isobaric control system inoperative so that the operation of the differential control system can be checked. In the "flight" position, the valve allows the regulator to function normally. The ground test valve should always be lockwired in the "flight" position unless being tested.

Cabin Air Pressure Safety Valve

The cabin air pressure safety valve (figure 14-15) is a combination pressure relief, vacuum relief, and dump valve. The pressure relief valve prevents cabin pressure from exceeding a predetermined differential pressure above ambient pressure. The vacuum relief prevents ambient pressure from

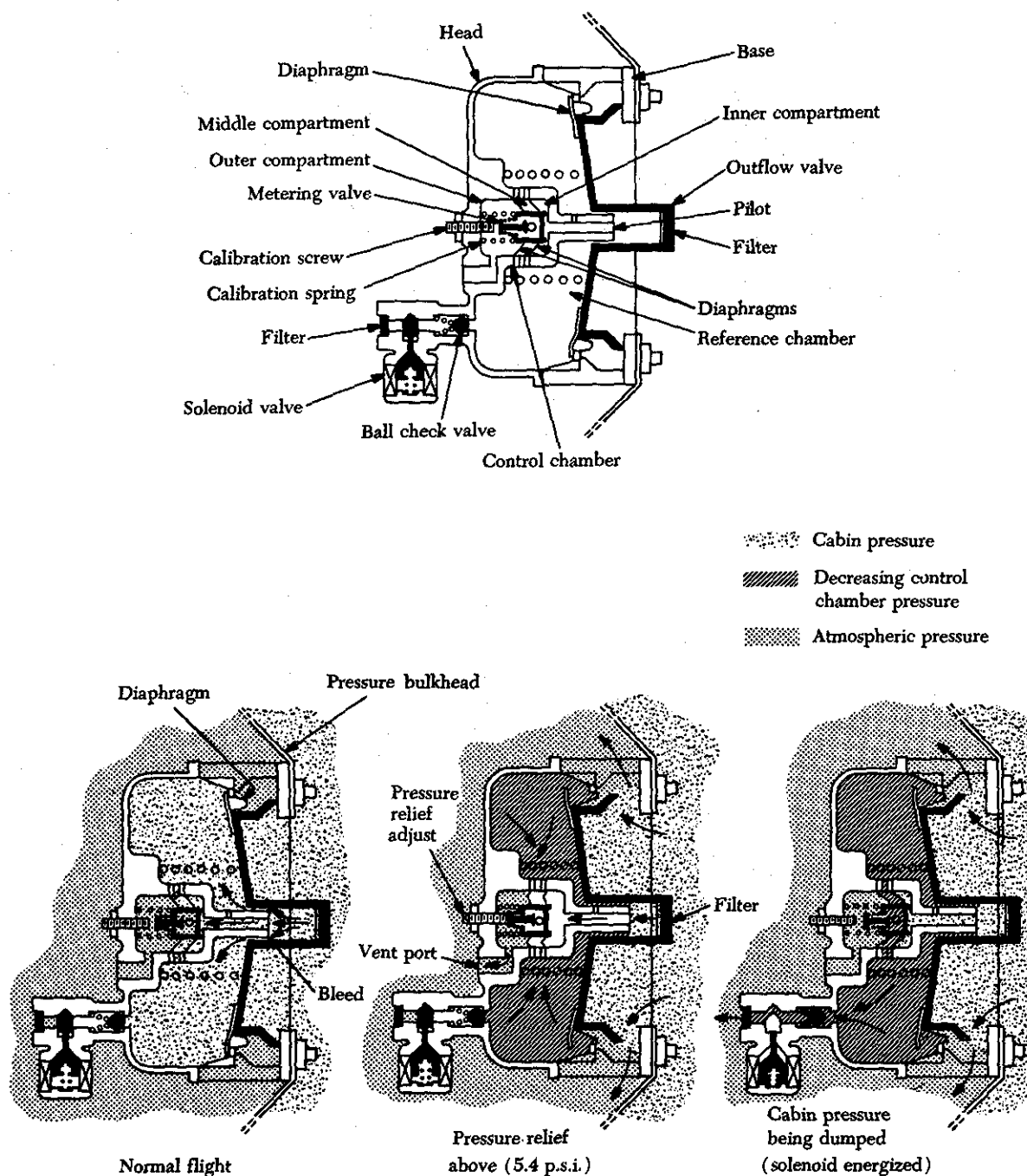


FIGURE 14-15. Cabin air pressure safety valve.

exceeding cabin pressure by allowing external air to enter the cabin when ambient pressure exceeds cabin pressure. The dump valve illustrated is actuated by the cockpit control switch. When this switch is positioned to "ram," a solenoid valve opens, causing the valve to dump cabin air to atmosphere. On some installations a manual system,

using cables and bellcranks, is provided to actuate the dump valve.

The safety valve consists of an outflow valve section and a control chamber. The outflow valve section and the control chamber are separated by a flexible pressure-tight diaphragm. The diaphragm is exposed to cabin pressure on the outflow valve side

and control chamber pressure on the opposite side. Movement of the diaphragm causes the outflow valve to open or close. A filtered opening in the outflow valve allows cabin air to enter the reference chamber. The outflow valve pilot extends into this opening to limit the flow of air into the chamber. Air pressure inside the reference chamber exerts a force against the inner face of the outflow valve to aid spring tension in holding the valve closed. The pressure of cabin air against the outer face of the outflow valve provides a force opposing spring tension to open the valve. Under normal conditions, the combined forces within the reference chamber are able to hold the outflow valve in the "closed" position. The movement of the outflow valve from closed to open allows cabin air to escape to atmosphere.

The head incorporates an inner chamber, called the pressure relief control chamber. Within the control chamber are located the two pressure relief diaphragms, the calibration spring, the calibration screw, and the spring-loaded metering valve. The action of these components within the chamber controls the movement of the outflow valve during normal operation.

The two diaphragms form three pneumatic compartments within the control chamber. The inner compartment is open to cabin pressure through a passage in the outflow valve pilot. The middle compartment is open to the reference chamber and is vented to the outer compartment through a bleed hole in the metering valve. The flow of reference chamber air from the middle compartment to the outer compartment is controlled by the position of the metering valve, which is spring-loaded to a normally closed position. The outer compartment, in which the calibration spring and screw are located, is opened to atmosphere through a passage in the head. Atmospheric pressure, reflected against the diaphragms, aids the calibration spring in keeping the metering valve closed. Cabin pressure, acting on the diaphragms through the inner compartment, tries to open the metering valve by moving it back against the calibration screw. Under normal conditions, the combined forces of atmospheric pressure and the calibration spring hold the metering valve away from the calibration screw, keeping it closed.

Pressure relief occurs when the cabin pressure exceeds atmospheric pressure by a predetermined value. At this point, cabin pressure overcomes the combined forces of atmospheric pressure and spring

tension in the control chamber, moving the metering valve back against the calibration screw, opening the metering valve. With the valve open, reference chamber air can escape through the outer compartment to the atmosphere. As the reference chamber air pressure is reduced, the force of cabin pressure against the outflow valve overcomes spring tension and opens the valve, allowing cabin air to flow to atmosphere. The rate-of-flow of cabin air to atmosphere is determined by the amount the cabin-to-atmosphere pressure differential exceeded the calibration point. As cabin pressure is reduced, the forces opening the valve will be proportionately reduced, allowing the valve to return to the normally closed position as the forces become balanced.

In addition to the automatic operating provisions just described, the valve includes provisions for electrical activation to the dump position. This is accomplished by a passage in the head that allows reference chamber air to vent directly to atmosphere. The flow of air through the passage is controlled by a ball-check valve and an air solenoid valve. The solenoid valve is spring-loaded to a normally closed position. When the solenoid valve is opened by positioning the cockpit pressure switch to "ram," air flows from the reference chamber, decreasing the reference pressure and allowing the outflow valve to open and dump cabin air.

It should be remembered that the foregoing description of a pressure control system is for illustrative purposes and should not be construed to represent any particular make or model aircraft. Always refer to the applicable manufacturer's manual for the system details and limitations for the aircraft with which you are concerned.

AIR DISTRIBUTION

The cabin air distribution system includes: (1) Air ducts, (2) filters, (3) heat exchangers, (4) silencers, (5) nonreturn (check) valves, (6) humidifiers, (7) mass flow control sensors, and (8) mass flow meters. The distribution system shown in figure 14-16 is typical of the system used on small turboprop aircraft.

Air enters the cabin supercharger through a screen-covered opening in the left engine oil cooler airscoop. If the air inlet screen ices over, a spring-loaded door beside the screen opens allowing air to bypass the screen. From the cabin supercharger, the air passes through a firewall shutoff valve, a pressure relief valve, and a silencer which dampens the supercharger noise and pulsations. The air then

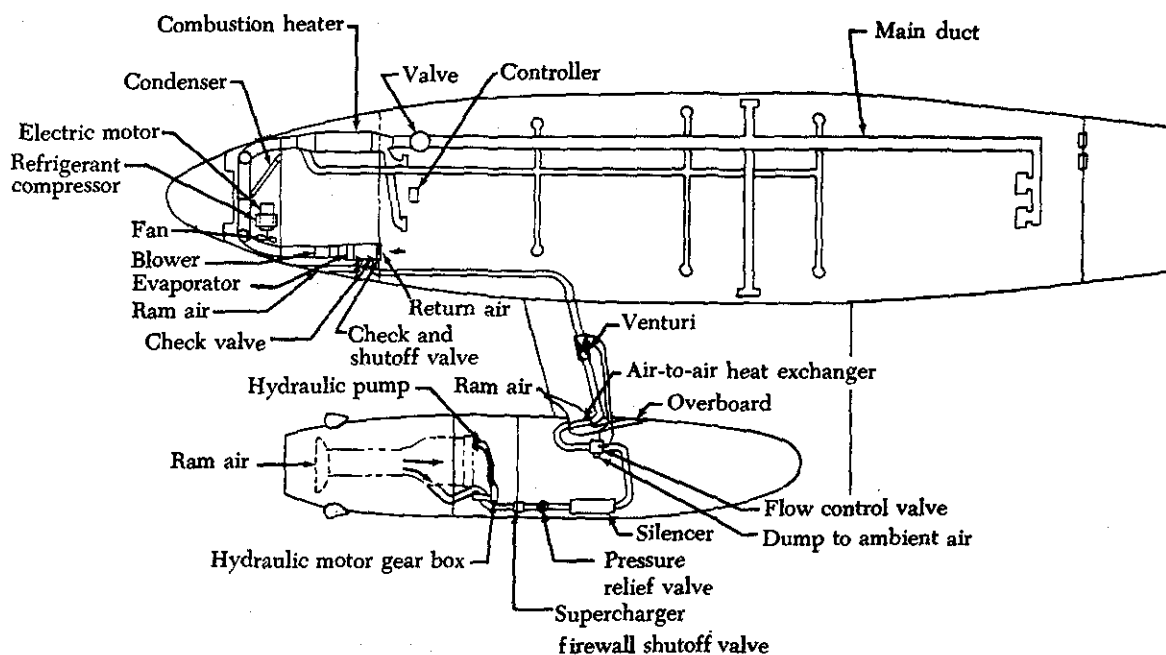


FIGURE 14-16. Typical air distribution system.

passes through a flow control valve which governs the airflow rate to maintain the maximum pounds per minute airflow.

Air Ducts

Ducts having circular or rectangular cross sections are most frequently used in air distribution systems. Circular ducts are used wherever possible. Rectangular ducts are generally used where circular ducts cannot be used because of installation or space limitations. Rectangular ducts may be used in the cabin where a more pleasing appearance is desired.

Distribution ducts for various cabin zones, individual air outlets for passengers, and window demisters can have various shapes. Examples of circular, rectangular, elliptical and profiled ducts are illustrated in figure 14-17.

Cabin air supply ducts are usually made from aluminum alloys, stainless steel, or plastic. Main ducts for air temperatures over 200° C. are made from stainless steel. Those parts of the ducting where the air temperature does not exceed 100° C. are usually constructed from soft aluminum. Plastic ducts, both rigid and flexible are used as outlet ducts to distribute the conditioned air.

Since heated air is routed throughout the duct system, it is important that the ducts be permitted to grow (expand through heating) and to shrink

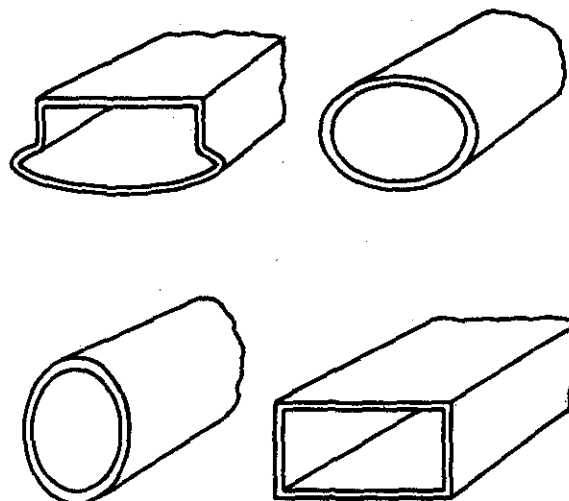


FIGURE 14-17. Cross sections of air distribution ducts.

again when the air cools down. This expansion and contraction must take place without loss of the pressure-tight integrity of the ducts. Expansion bellows (figure 14-18) are incorporated at various places throughout the duct system to permit the ducts to expand or contract.

In general, supports are necessary on both sides of a connecting bellows, a fixed support on one side to prevent duct movement, and a sliding support plus a fixed support on the other side. The sliding

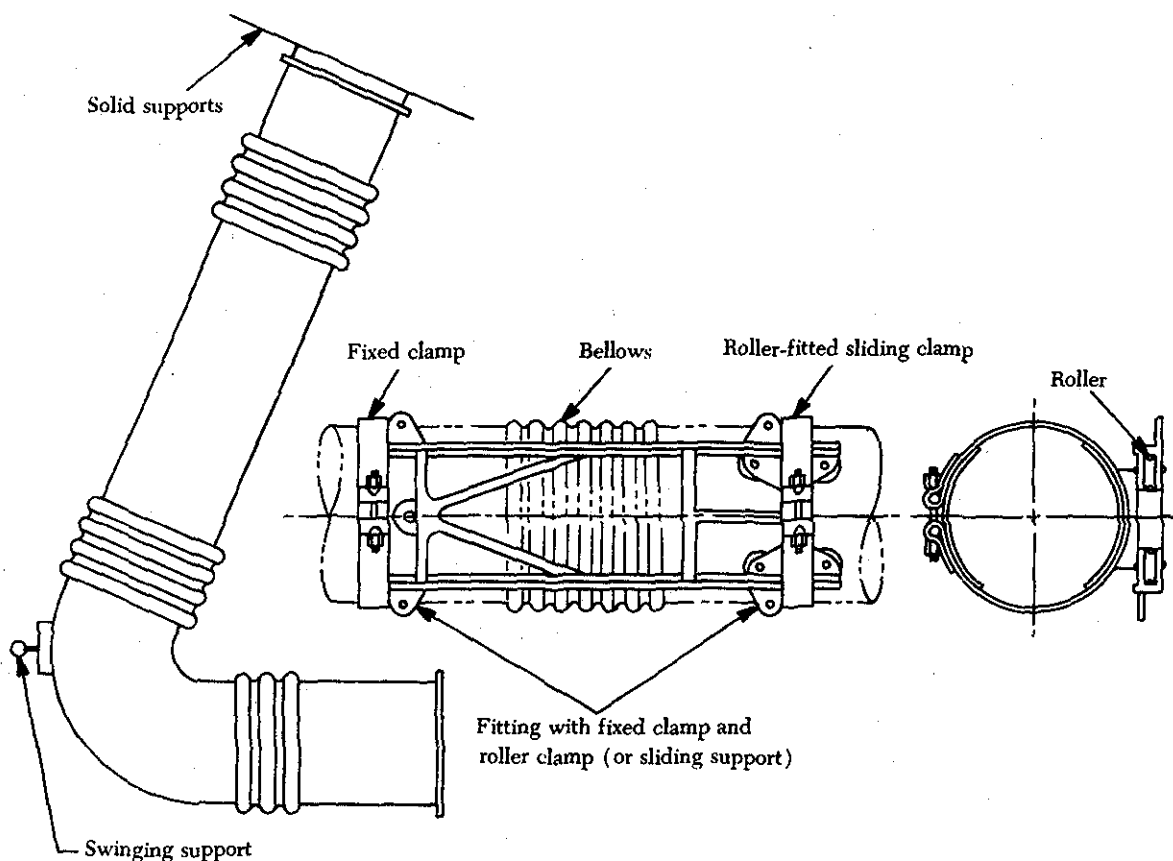


FIGURE 14-18. Expansion bellows and duct supports.

support permits movement of the bellows while the duct section is under pressure. Typical duct support systems are illustrated in figure 14-18.

Whenever a duct is angled, means are provided to take care of the end forces which tend to push the duct sections apart. This can be accomplished with external swinging supports which attach the duct to rigid airframe structure (figure 14-19).

In some instances a connecting link is incorporated within the duct itself to transmit end loads. The tension link within the bellows resembles a single link of chain that joins two segments of ducts. Figure 14-20 illustrates one such connecting link.

Filters

The air delivered to a pressurized cabin from a supercharger or engine compressor may contain dust particles, oil mist, or other impurities. Unfiltered air which contains a considerable amount of impurities usually has an offensive odor and causes

headache and nausea. Filters are generally incorporated into the ducting to clean the air.

AIR CONDITIONING SYSTEM

The function of an air conditioning system is to maintain a comfortable air temperature within the aircraft fuselage. The system will increase or decrease the temperature of the air as needed to obtain the desired value. Most systems are capable of producing an air temperature of 70° to 80° F. with normally anticipated outside air temperatures. This temperature-conditioned air is then distributed so that there is a minimum of stratification (hot and cold layers). The system, in addition, must provide for the control of humidity, it must prevent the fogging of windows, and it must maintain the temperature of wall panels and floors at a comfortable level.

In a typical system the air temperature is measured and compared to the desired setting of the temperature controls. Then, if the temperature is

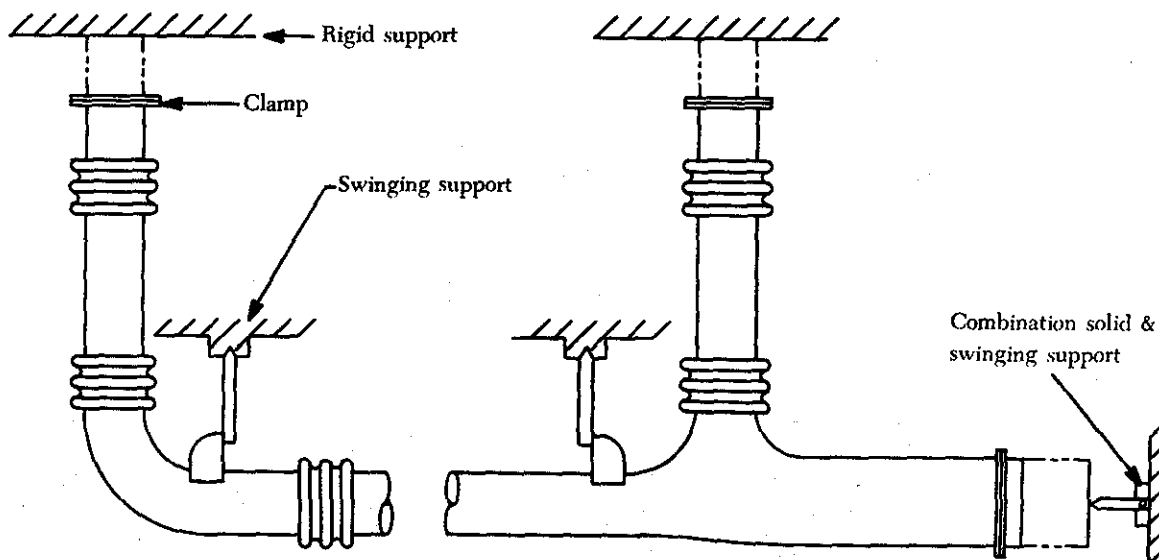


FIGURE 14-19. Typical supports for angled ducts.

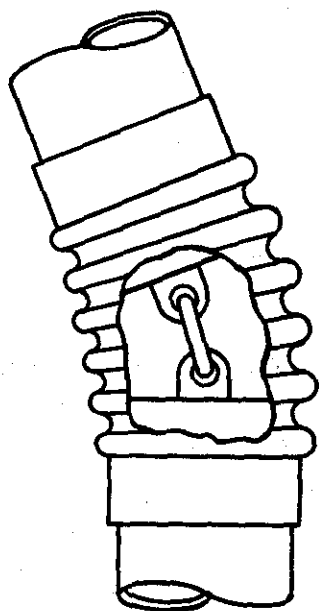


FIGURE 14-20. Connecting link inside of bellows.

not correct, heaters or coolers are set into operation to change the air temperature, and the air is mixed together to create a uniform temperature in the cabin. In summary, an air conditioning system is designed to perform any or all of the following functions: (1) Supply ventilation air, (2) supply heated air, and (3) supply cooling air.

Ventilation Air

Ventilation air is obtained through ram air ducts

installed in the leading, lower, or upper surfaces of the aircraft or through other vents in the aircraft skin. Air entering these openings usually passes into and through the same duct system that is used for heating and cooling. On some aircraft, recirculating fans or blowers are present in the system to assist in circulating the air. Many aircraft have ground connections for receiving heated, cooled, or ventilating air from ground servicing equipment.

HEATING SYSTEMS

A large part of the heating requirements for the conditioned air is accomplished automatically when the air is compressed by the cabin superchargers. In many cases additional heat need not be added. Compression of the air often provides more than the necessary heating. Consequently, cooling, to some degree, is required even when the outside air temperature is not high.

When a degree of heating in addition to that obtained from the "heat of compression" is needed, one of the following types of systems is put into operation: (1) Gasoline combustion heaters, (2) electric heaters, (3) re-cycling of compressed air, and (4) exhaust gas air-to-air heat exchanger.

Combustion Heater

Combustion heaters operate similarly to the burner section of a turbojet engine. Gasoline is injected into the burner area under a pressure which breaks up the fuel into a fine mist. Combustion air is supplied to the burner by means of a ram air scoop or an electric motor driven fan. Ignition is supplied by continuous sparking of a special

spark plug. The combustion of fuel and air takes place continuously. The temperature output of the heater is controlled by a cycling process whereby combustion is turned on and off for short periods of time depending upon the heating required. The air which eventually mixes with the cabin air is routed around the burner section in a separate air passage. This ventilating air picks up heat from the burner by convection through the metal walls of the burner. The burner combustion gasses are exhausted overboard to prevent carbon monoxide contamination of the cabin.

Various automatic combustion heater controls prevent operation of the heater when dangerous conditions exist. As examples, the flow of fuel is cut off if there is insufficient combustion air, insuffi-

cient ventilating air, and in some cases if the ignition system is not operating. Other controls prevent too rapid heating of the combustion chamber and prevent exceeding a maximum output temperature.

Electric heaters may be in the form of air duct heaters or electric radiant panels. The duct heater incorporates a series of high-resistant wire coils located in an air supply duct. When electric power is applied to the coils, they become hot. The air flowing through the duct carries the heat to the area where it is needed. Most duct heaters require the use of a fan to ensure sufficient airflow over the coils. Without the aid of the fan-produced airflow, the coils would fail due to overheating. Usually an electrical circuit is used which prevents heater operation unless the fan is in operation.

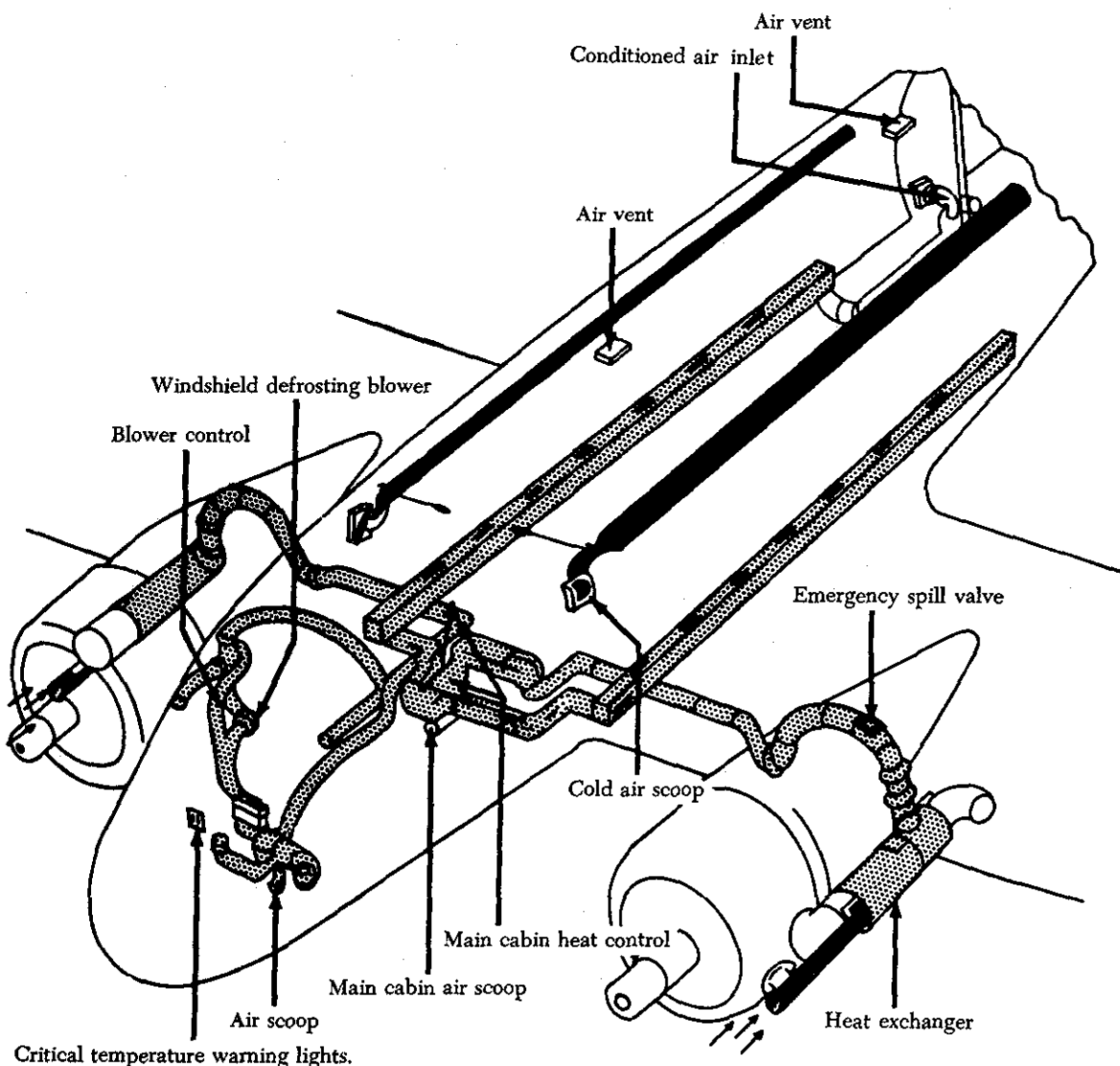


FIGURE 14-21. Engine exhaust heater system.

Radiant Panels

Radiant panels consist of wall and floor surfaces which have electric wires embedded in the panel material. When electric power is applied to the wires, the wires and panel surface become hot. This type panel supplies heat to the cabin air principally by radiation.

Electric Heaters

Electric heating systems require the expenditure of large amounts of electrical power. They cannot be used if the electrical system has limited capacity. Electric heating systems, however, are quick acting and can be used to preheat the aircraft on the ground before the engines are started if an adequate electric ground power source is available.

Compressed Air Heating

Some turbojet aircraft use a heating system in which the hot compressed air output of the cabin compressor is re-routed back into the compressor inlet. This double compression raises the temperature of the air to a sufficiently high degree so that other types of heating are usually not necessary.

Exhaust Gas Heaters

A relatively simple heating system used on a few large aircraft utilizes the engine exhaust gases, figure 14-21, as a heat source. This system is particularly effective on aircraft where the engine exhaust is ejected through a long tailpipe. A hot air muff or jacket is installed around the tailpipe. Air

routed through the hot air muff picks up heat by convection through the tailpipe material. This heated air is then routed to an air-to-air heat exchanger, where its heat is given up to the air going to the cabin. By using the air-to-air heat exchanger in addition to the hot air muff, the danger of carbon monoxide entering the cabin is minimized.

Regardless of the type, heating systems provide heated air for comfort and furnish heat for defrosting, deicing, and anti-icing of aircraft components and equipment. Nearly all types of heating systems use the forward motion of the aircraft to force conditioned air to various points on the aircraft. A heating system consists of a heating unit and the necessary ducting and controls. The units, ducts, and controls used will vary considerably from system to system.

COMBUSTION HEATERS

The number and size of combustion heaters used in a particular aircraft depend upon its size and its heating demands. These heaters are installed singly or in combination to fit the heating requirements of specific aircraft. A large single heater or several smaller heaters may be used. Regardless of size, every combustion heater needs four things for operation: (1) Fuel to burn, (2) ignition to ignite the fuel, (3) combustion air to provide the oxygen required to support the flame, and (4) ventilating air to carry the heat to the places where it is needed.

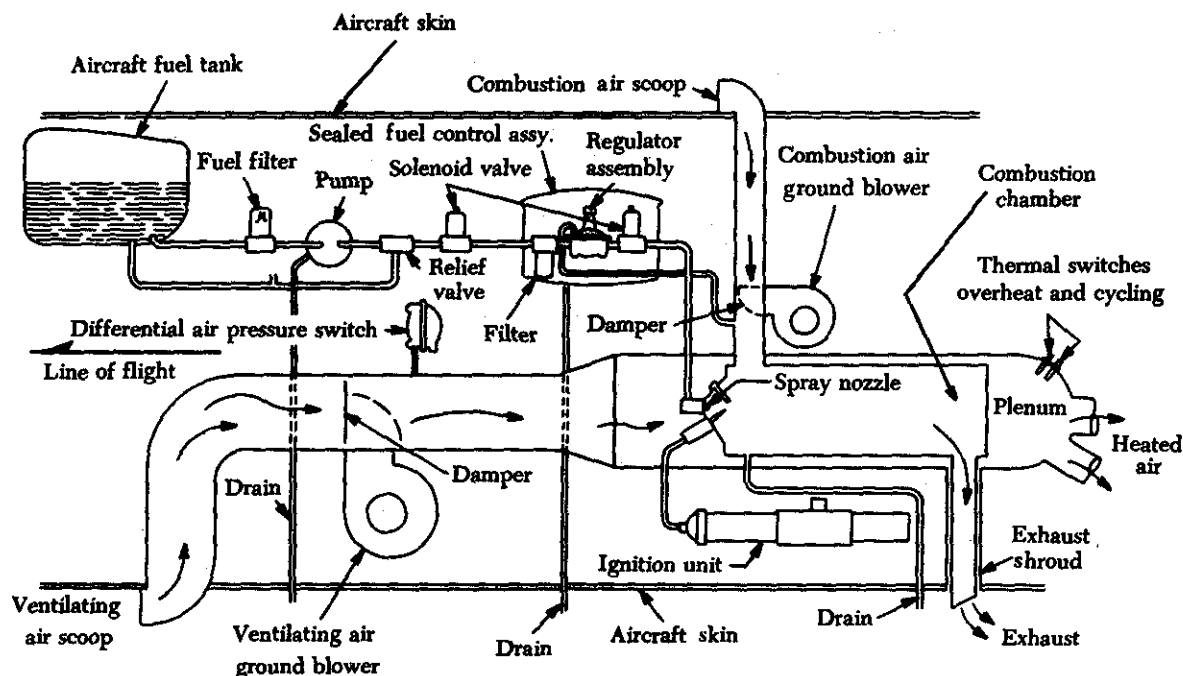


FIGURE 14-22. Heater installation schematic.

All combustion heaters are similar in operation and construction features. The major differences are in the methods of introducing fuel and in the location of units and accessories. The various components that comprise a complete aircraft heating system are shown schematically in figure 14-22.

Heater Fuel System

The fuel used in the heaters is supplied in most cases from the same fuel tanks which supply the engines. Fuel flows from the tank to the heater by gravity or is pumped there by a fuel pump. Like the fuel which flows to the aircraft engine, heater fuel must first pass through a filter to remove impurities. If foreign particles are not removed, they may eventually clog heater system units and prevent heater operation.

After the fuel is filtered, it flows through a fuel solenoid valve and metering nozzle. There are several types of these valves and metering nozzles. Regardless of type, they usually have the same purpose, to maintain a constant volume at the fuel outlet to the combustion chamber. This uniform volume, in combination with a fixed combustion airflow, ensures a relatively constant fuel/air ratio to the heater. The result is a steady heater output.

To increase or decrease the cabin temperature, the heaters are permitted to operate longer when more heat is needed and for shorter periods of time when less heat is desired. On most heater systems this is accomplished automatically by an amplifier connected to temperature-sensing devices or by cycling switches which open and close the circuit to the fuel solenoid valve. Thus the heater cycles on and off to maintain the temperature selected on a temperature control rheostat located in the cabin.

Most heater systems also include overheat switches in each heater outlet to automatically turn off the heater fuel supply when the temperature reaches about 350° F. It can be seen that control of the heater fuel supply is necessary, not only for normal operation of the heater but also for stopping it when overheated.

Another essential unit of the heater fuel system is the one that feeds fuel into the combustion chamber. Depending on the installation, it may be either a spray nozzle or a vapor wick. The spray nozzle (figure 14-23) is shaped so as to inject a fine, steady spray into the stream of combustion air, where it is ignited by a spark plug.

The vapor wick is made of asbestos contained in a circular flanged casting or of stainless steel con-

tained in a vertical standpipe. The latter type is illustrated in figure 14-24.

A preheater, in the form of an electrical wire coiled around the fuel line, is used with some heaters having a vapor wick. It warms the fuel to speed vaporization and aids ignition when the outside temperature is below zero. Its use is usually limited to 2 min., because longer operation would damage the wire coil.

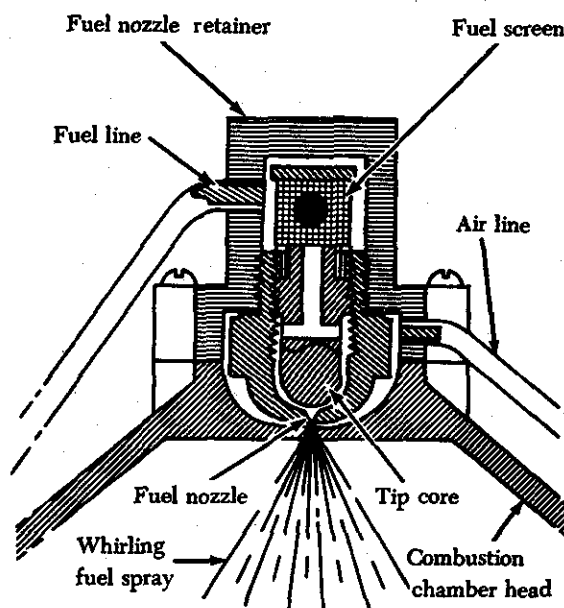


FIGURE 14-23. Typical heater spray nozzle assembly.

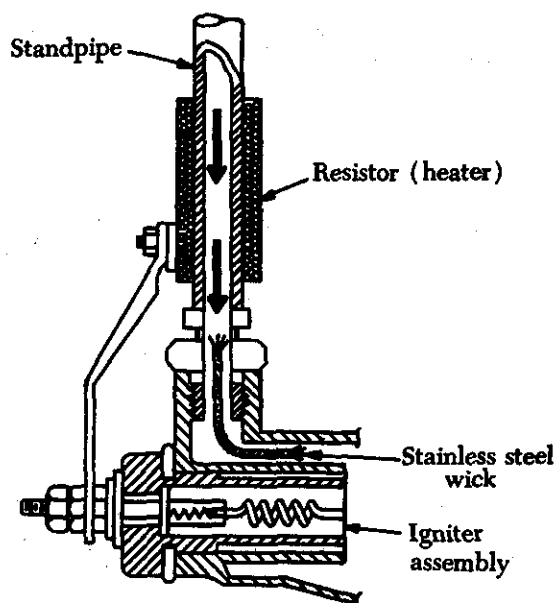


FIGURE 14-24. Stainless steel vapor wick.

Ignition System

High voltage for heaters using spark plug igniters is supplied either by a high-potential ignition unit operating from the 28-v. d.c. aircraft supply or by ignition transformers operating from a 115-v. a.c. aircraft source. The 28-v. d.c. ignition unit consists chiefly of a vibrator and step-up coil which produces a high-voltage spark at high frequency. A shielded lead is used to connect the step-up coil to the spark plug. The spark is produced between the center spark plug electrode and a ground electrode. About the same result is obtained where ignition transformers are used. Here, however, power is supplied by the 115-v., 400-Hz main inverter a.c. system. This is routed to the transformers, where it is stepped up to the very high voltage required to jump the spark gap at the spark plug. But whether a d.c. or an a.c. source is used to fire the spark plug, ignition is continuous during heater operation. This continuous operation prevents fouling of the spark plug electrodes.

It is the arrangement of the electrodes that makes the difference in the types of spark plugs used in aircraft combustion heaters. One type of spark plug is shown in figure 14-25A. This is known as a dual-electrode spark plug. Another type of plug to be found on combustion heaters is the shielded elec-

trode plug (figure 14-25B). In this plug, the ground electrode forms a shield around the center electrode.

Although spark plug igniters differ somewhat in appearance, most glow coil igniters look similar to that shown in figure 14-25C. They consist of a resistance wire wound into a coil around a pin extending from the body of the igniter. The outer end of the coil is connected to the pin, thus providing both support and electrical continuity. The body of the igniter is fitted with two terminals, which are connected across the coil, and is threaded to provide for installation. The glow coil operates from the 24- or 28-v. d.c. power supply on the aircraft. The direct current causes the coil to become red hot, thereby igniting the fuel/air mixture until the heater is operating at a temperature sufficient to maintain the flame after the glow coil is turned off. A thermal cutout switch breaks the circuit to the glow coil when this temperature is reached. This prolongs the life of the igniter.

Another type of plug used is a single electrode type (not shown). The ground electrode used with this type of plug is a separate installation attached to the heater at an angle that will provide an airgap between the plug's electrode and ground.

Combustion Air System

Combustion air for each cabin heater is received through either the main air intake or through a separate outside scoop. On both pressurized and unpressurized aircraft it is provided by ram pressure during flight and by ground blowers during ground operation. To prevent too much air from entering the heaters as air pressure increases, either a combustion air relief valve or a differential pressure regulator is provided. The air relief valve is located in the line leading from the ram-air intake duct and is spring-loaded to dump excess air into the heater exhaust gas stream. The differential pressure regulator is also located in the combustion air intake line, but it controls the amount of air reaching the combustion chamber in a slightly different manner.

While the relief valve takes a large volume of air and bypasses the amount not needed, the pressure regulator allows only the needed amount of air to enter its intake in the first place. It does this by the use of a diaphragm and spring type control mechanism. One side of the diaphragm is vented to the heater intake air line and the other side to the heater exhaust gas line. Any change in the pressure

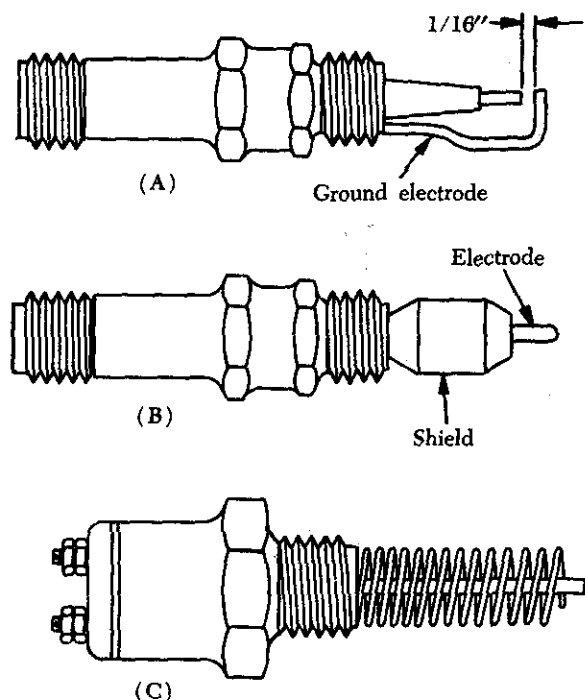


FIGURE 14-25. Heater ignition plugs.

drop between these points is corrected at the regulator by letting in more or less air as required. Thus, a constant combustion air pressure is provided to the heater. Coupled with a steady fuel flow, this constant air pressure makes possible a regulated flow of combustion gases through the combustion chamber and the connecting radiator. If a fire breaks out near the heater, a fire valve automatically stops the supply of combustion air to prevent spreading of the fire to the heating system.

A damper-type combustion air fire valve (figure 14-26) is located in the combustion air inlet of some heaters. It has two semicircular, spring-loaded segments soldered together to permit maximum air-flow through the combustion air duct. The segments will release to seal the duct when the solder melts at about 400° F.

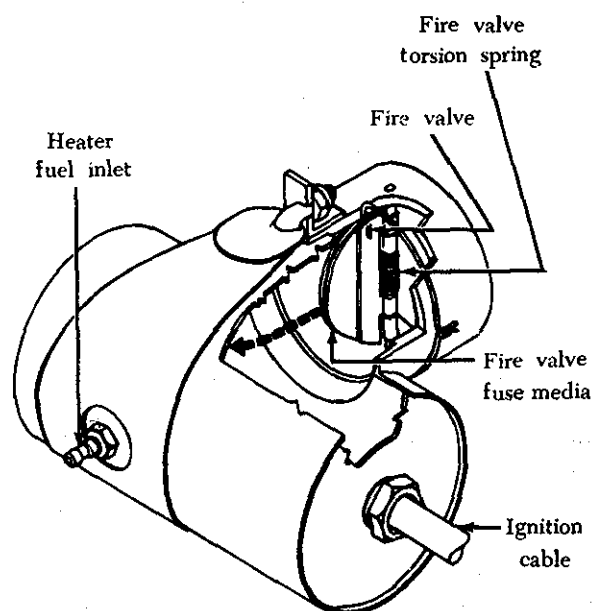


FIGURE 14-26. Cabin heater combustion air fire valve.

Ventilating Air

Ventilating air may come from one of three sources: (1) A blower for air circulation and heater operation on the ground, (2) a ram-air inlet, or (3) the cabin compressors on pressurized aircraft.

Ventilating air, ram or blower, enters at the burner head end of the heater and, passing over the heated radiator surfaces, becomes heated and passes through the outlet end into the plenum assembly and into the distribution system ductwork.

MAINTENANCE OF COMBUSTION HEATER SYSTEMS

Combustion heater components are subject to wear and damage which can result in system failure. When this occurs, troubleshooting procedures must be followed to isolate component failures. Then all damaged or excessively worn components must be replaced. During the replacement of the components, adjustments must be made to assure proper operation of the combustion heater system. Always follow the manufacturer's instructions when making any adjustments to a heater or heating system.

In this section, heater system adjustments which are representative of those performed by the aircraft mechanic are discussed. Keep in mind that the components of the system vary with the types of aircraft, and so do the adjustment procedures.

On some aircraft careful adjustment of cabin heat outlets is necessary to obtain uniform heat distribution. Some of the factors which cause the variation in distribution are: (1) The distance of the outlet from the source of heated air, (2) the cross sectional area of the outlet, (3) the space serviced by the outlet, and (4) any restrictions to airflow caused by duct size and routing.

Air mixing valves are installed in airborne heating systems so that hot and cold air can be mixed in the required proportions to maintain adequate heat. Some air mixing valves are preset on the ground and cannot be actuated during flight. External adjustments are provided on these valves to permit seasonal adjustment. During adjustment, the valves are set to a specified number of degrees from the fully closed position.

To assure the proper mixing of hot and cold air in motorized air mixing valves, adjustments are provided on each valve. The adjustments regulate the opening and closing positions of the valves.

Heater System Inspection

The inspection of combustion heater systems includes checking the air openings and outlets for obstructions. All controls are checked for freedom of operation. Turn on the fuel pump so that the fuel lines, solenoids, and valves can be checked for leakage. The heater unit is inspected for proper operation by turning it on and observing whether or not hot air comes out of the outlets. The outside of the heater unit is checked for signs of overheating. Any burned or darkened areas usually indicate a burned-through combustion chamber. Heaters dam-

aged by overheating should be replaced. When replacing a heater due to overheating, always determine the cause of the trouble. The faulty operation of some part of the system, such as stopped-up heater air inlet ducts or improperly operating switches, regulators, valves, or other units, is the most likely cause of damage. The automatic and overheat control devices should be operationally checked. The cabin heating ducts should be examined for tears, breaks, and ballooning. To guarantee fuel flow, the heater fuel filter element should be inspected for cleanliness and the fuel injection nozzle or glow coil for freedom from carbon deposits.

To obtain proper operation of combustion heaters under freezing conditions, a special winterization inspection should be performed. Check heater drain lines regularly for restrictions caused by ice formation. During low temperature operation below 0° C. (32° F.), water vapor in the combustion gases flowing through drain lines may condense and form ice. Under changing temperature conditions, water condenses and freezes in the ram and heater combustion sensing lines. Water produced during combustion may collect on the fuel nozzles and spark plug and form ice after the heater is turned off. This ice may be sufficient to make it difficult, if not impossible, to start the heater without preheating.

COOLING SYSTEMS

Air cooling systems are installed to provide a comfortable atmosphere within the aircraft both on the ground and at all altitudes. These systems keep the correct amount of air flowing through the interior of the aircraft at the right temperature and moisture content. Since the fuselage is a huge cavity, the capacity of the cooling system must be quite large. Several types of systems can be used to meet these requirements. Two of the more common types, air cycle and vapor cycle, are discussed in this section.

AIR CYCLE COOLING SYSTEM

An air cycle cooling system consists of an expansion turbine (cooling turbine), an air-to-air heat exchanger, and various valves which control airflow through the system. The expansion turbine incorporates an impeller and a turbine on a common shaft. High-pressure air from the cabin compressor is routed through the turbine section. As the air passes through the turbine, it rotates the turbine and the impeller. When the compressed air performs the work of turning the turbine, it undergoes a

pressure and temperature drop. It is this temperature drop which produces the cold air used for air conditioning.

Before entering the expansion turbine, the pressurized air is directed through an air-to-air heat exchanger. This unit utilizes outside air at ambient temperature to cool the compressed air. It should be evident that the heat exchanger can only cool the compressed air to the temperature of the ambient air temperature. The primary purpose of the heat exchanger is to remove the heat of compression so that the expansion turbine receives relatively cool air on which to start its own cooling process.

The impeller part of the expansion turbine can perform several functions. In some installations the impeller is used to force ambient air through the heat exchanger. In this manner, the efficiency of the heat exchanger is increased whenever the speed of the expansion turbine is increased. Other installations use the impeller to further compress the cabin supercharger air as an aid to forcing it through the heat exchanger and the turbine.

A valve controls the compressed airflow through the expansion turbine. To increase cooling, the valve is opened to direct a greater amount of the compressed air to the turbine. When no cooling is required, the turbine air is shut off. Other valves, operated in conjunction with the turbine air valve, control the flow of ambient air through the heat exchanger. The overall control effect of these valves is to increase the heat exchanger cooling airflow at the same time increased cooling is obtained at the turbine.

The power required to drive the air cycle system is derived entirely from the cabin supercharger compressed air. Use of the air cycle system, therefore, imposes an increased load on the superchargers. As more cooling is demanded from the turbine, a greater back pressure is placed on the superchargers, which must work harder to supply the air demands. It is often necessary to make a choice between the desired amount of cooling and the desired degree of cabin pressurization, and a compromise is made by reducing the demand for one or the other. Maximum cooling and maximum pressurization cannot be obtained at the same time. Attempts to obtain both will cause the supercharger to surge or operate in an otherwise unsatisfactory manner.

System Operation

This description of the operation of an air conditioning system is intended to provide an under-

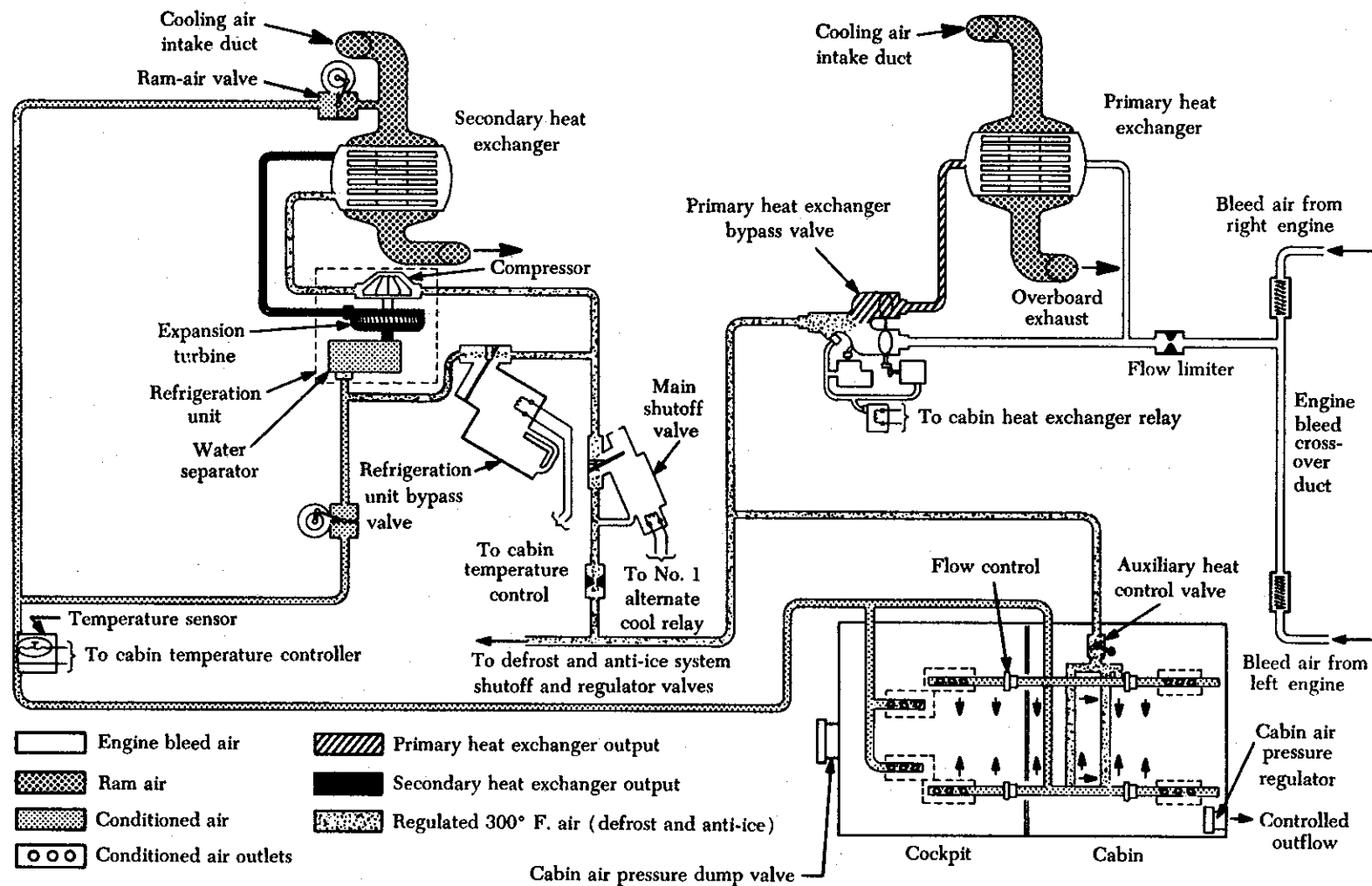


FIGURE 14-27. Cabin air conditioning and pressurization system flow schematic.

standing of the manner in which the system is controlled, the functions of the various components and subassemblies, and their effect on total system operation. Figure 14-27 is a schematic of a typical system. Frequent reference to the schematic should be made during study of the following operational description.

The system is composed of a primary heat exchanger, primary heat exchanger bypass valve, flow limiters, refrigeration unit, main shutoff valve, secondary heat exchanger, refrigeration unit bypass valve, ram-air shutoff valve, and an air temperature control system. A cabin pressure regulator and a dump valve are included in the pressurization system.

Air for the cabin air conditioning and pressurization system is bled from the compressors of both engines. The engine bleed lines are cross-connected and equipped with check valves to ensure a supply of air from either engine.

A flow-limiting nozzle is incorporated in each supply line to prevent the complete loss of pressure in the remaining system if a line ruptures, and to prevent excessive hot air bleed through the rupture.

In reading the schematic, in figure 14-27, the initial input of hot air is indicated on the right-hand side. The flow is depicted across the page through each unit, in turn, and back to the squares on the lower right-hand side which represent the cockpit and cabin.

Air from the engine manifolds is ducted through a flow limiter to the primary heat exchanger and its bypass valve simultaneously. Cooling air for the heat exchanger is obtained from an inlet duct and is exhausted overboard.

The air supply from the primary heat exchanger is controlled to a constant temperature of 300° F. by the heat exchanger bypass valve. The bypass valve is automatically controlled by upstream air pressure and a downstream temperature-sensing element. These provide temperature data to cause the valve to maintain the constant temperature by mixing hot engine bleed air with the cooled air from the heat exchanger.

The cabin air is next routed through another flow limiter and a shutoff valve. The shutoff valve is the main shutoff valve for the system and is controlled from the cockpit.

From the shutoff valve, the air is routed to the refrigeration unit bypass valve, to the compressor section of the refrigeration unit, and to the second-

ary heat exchanger. The bypass valve automatically maintains compartment air at any preselected temperature between 60° F. and 125° F. by controlling the amount of hot air which bypasses the refrigeration unit and mixes with the refrigeration unit output.

Cooling air for the secondary heat exchanger core is obtained from an inlet duct. Some installations use a turbine-driven fan to draw air through the heat exchanger; others use a hydraulically driven blower. After cooling the cabin air, the cooling air is exhausted overboard.

As the cabin air leaves the secondary heat exchanger, it is routed to the expansion turbine, which is rotated by the air pressure exerted on it. In performing this function, the air is further cooled before entering the water separator, where the moisture content of the air is reduced. From the water separator the air is routed through the temperature sensor to the cabin.

Air enters the cabin spaces through a network of ducts and diffusers and is distributed evenly throughout the spaces. Some systems incorporate directional vents that can be rotated by the cabin occupants to provide additional comfort.

An alternate ram-air system is provided to supply the cabin with ventilating air if the normal system is inoperative or to rid the cabin areas of smoke, foul odors, or fumes which might threaten comfort, visibility, or safety.

The air conditioning and the ram-air systems are controlled from a single switch in the cockpit. This switch is a three-position switch for selecting off, normal, and ram. In the "off" position (under normal conditions) all cabin air conditioning, pressurization, and ventilating equipment is off. In the "normal" position (under normal conditions) the air conditioning and pressurization equipment is functioning normally and ram air is off. In the "ram" position (under normal conditions) the main shutoff valve closes, and the cabin air pressure regulator and the cabin safety dump valve are opened. This allows ram air from the secondary heat exchanger cooling air inlet duct to be routed into the cabin air supply duct for cabin cooling and ventilation.

With the air pressure regulator and the safety dump valve energized open, existing cabin air and incoming ram air are constantly being dumped overboard, ensuring a steady flow of fresh air through the cabin.

A duct incorporated in the air conditioning system between the constant-temperature line downstream from the primary heat exchanger bypass valve and the cabin compartment supplies hot air for supplemental heating. Control of this air is provided by the auxiliary heat control valve, which is a butterfly type valve. The heat control valve is controlled by a manually operated heat control handle, which is connected by cable to a control arm mounted on the valve.

The temperature control system consists of a cabin temperature controller, a temperature selector knob, a two-position temperature control switch, a modulating bypass valve, and a control network. When the temperature control switch is in the "auto" position, the bypass valve will seek a valve gate position which will result in a duct temperature corresponding to the temperature controller setting. This is accomplished through the control network, which transmits signals from the sensing element to the cabin temperature controller, which then electrically positions the valve in relation to the settings of the temperature control knob. With the temperature control switch in the "man." position, the controller will control the bypass valve directly, without reference to the duct temperature. In this mode of operation the desired temperatures are maintained by monitoring the air temperature knob as varying conditions alter cabin temperature.

AIR CYCLE SYSTEM COMPONENT OPERATION

Primary Heat Exchanger

This unit, illustrated in figure 14-28, reduces the temperature of engine bleed air or supercharger discharge air by routing it through the veins in the core of the heat exchanger. During flight the core is cooled by ram air. The amount of air to be cooled in the primary heat exchanger is controlled by the primary heat exchanger bypass valve.

Primary Heat Exchanger Bypass Valve

The primary heat exchanger bypass valve (figure 14-29) is located in the high-pressure duct at the primary heat exchanger outlet. As previously stated, it modulates and controls the flow of primary heat exchanger air and primary heat exchanger bypass air to maintain a constant output air temperature of 300° F. The unit consists essentially of a regulator body assembly which contains a pressure regulator, a temperature control actuator, a solenoid valve, and a pneumatic thermostat. The body assembly of the unit contains two inlet ports marked "hot" and

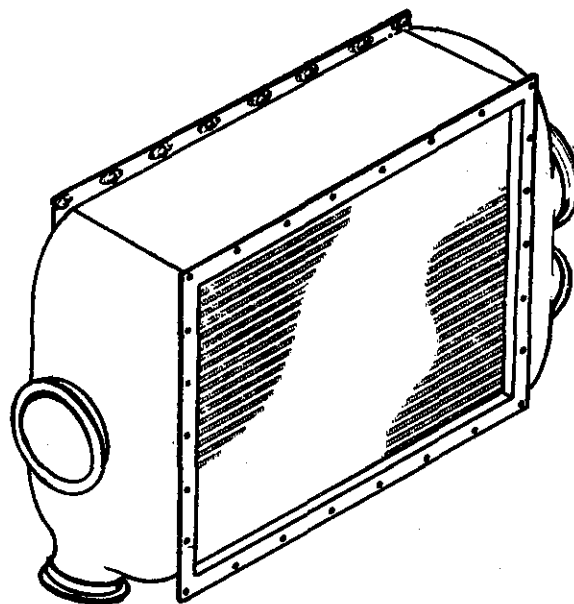


FIGURE 14-28. Primary heat exchanger.

"cold" and one outlet port. The two inlet ports incorporate butterfly valves, which are mounted on serrated shafts that extend across the width of the housing assembly and are attached to a common actuator control arm. The butterflies are positioned at 90° to each other and operate in such a manner that when one moves toward the "open" position the other moves toward the "closed" position. The actuator shaft contains an adjustable stop screw, which limits actuator travel, and pointers for indicating the position of the butterflies.

The temperature control actuator is mounted on the bypass valve body and consists of a housing and cover containing a spring-loaded diaphragm assembly. The diaphragm assembly is attached to the butterfly control arm and divides the actuator into a control pressure chamber and an ambient sensing chamber. The ambient chamber contains the diaphragm spring and the actuator rod.

As shown in the schematic in figure 14-29, pressure from the primary heat exchanger is routed through a filter and on through the pressure regulator into the control pressure chamber of the temperature control actuator. This internal pressure is called reference pressure. The reference pressure applied against the actuator diaphragm controls the position of the butterflies, which in turn controls the proportion of hot air from the bypass line and cooled air from the heat exchanger. The entire operation of the bypass valve is centered about the

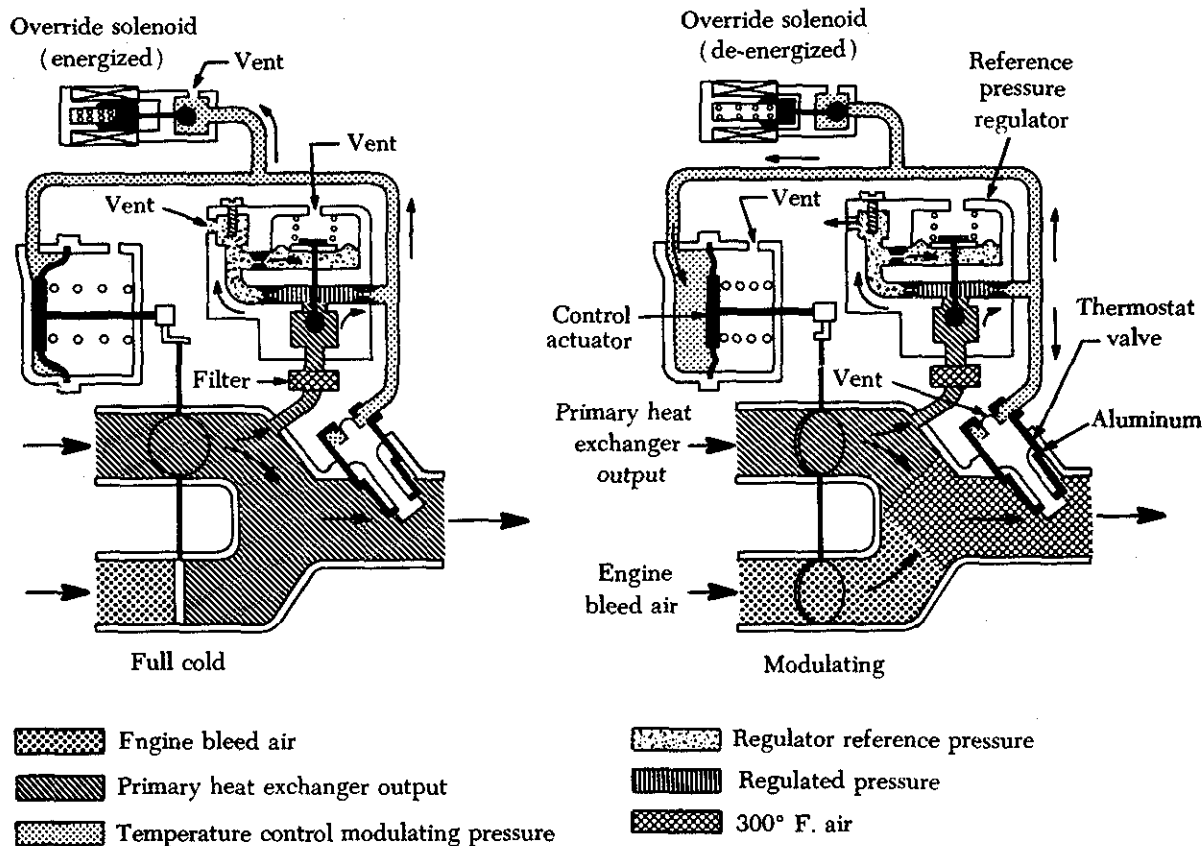


FIGURE 14-29. Primary heat exchanger bypass valve.

proportion of reference air pressure to heat. The greater the reference pressure that is supplied to the control actuator, the higher will be the temperature of the output air.

A pressure regulator is provided in the bypass valve to ensure a supply of reference air pressure to the control actuator on a schedule that eliminates the effect of altitude on the controlled temperature. As the aircraft altitude increases, the constant reference pressure in the control actuator tends to move the control actuator diaphragm even further toward the ambient side. This moves the butterflies in a direction that causes the outlet temperature to rise. The pressure regulator offsets this condition with the help of the pneumatic thermostat.

The variable-orifice type thermostat consists of a spring-loaded, ball-type valve and seat assembly housed in a core assembly. The core assembly is composed of a high-expansion element (aluminum) and a low-expansion element (Invar). As can be seen in the diagram (figure 14-29), the aluminum housing and the end of the Invar core extend into the outlet duct. Linear expansion of the aluminum

housing moves the Invar core and ball-type valve assembly from the valve seat. This movement vents reference air pressure to the atmosphere. The resulting pressure applied against the temperature control actuator diaphragm controls the position of the butterflies.

The bypass valve regulating mechanism may be set to deliver cold air only by energizing the electromagnetic valve (override solenoid valve). The electromagnetic valve vents all reference air pressure to atmosphere when energized. With no reference air pressure, the spring-loaded diaphragm in the temperature control actuator returns the butterflies to the "full cold" position.

The electrical circuitry is so arranged that the solenoid can be energized only if the windshield anti-ice control switch is in the "off" position. This ensures a supply of hot air for anti-ice operation.

Shutoff Valve

The shutoff valve (figure 14-30), located in the air supply duct to the refrigeration unit, controls the air pressure to that unit. It is also the main

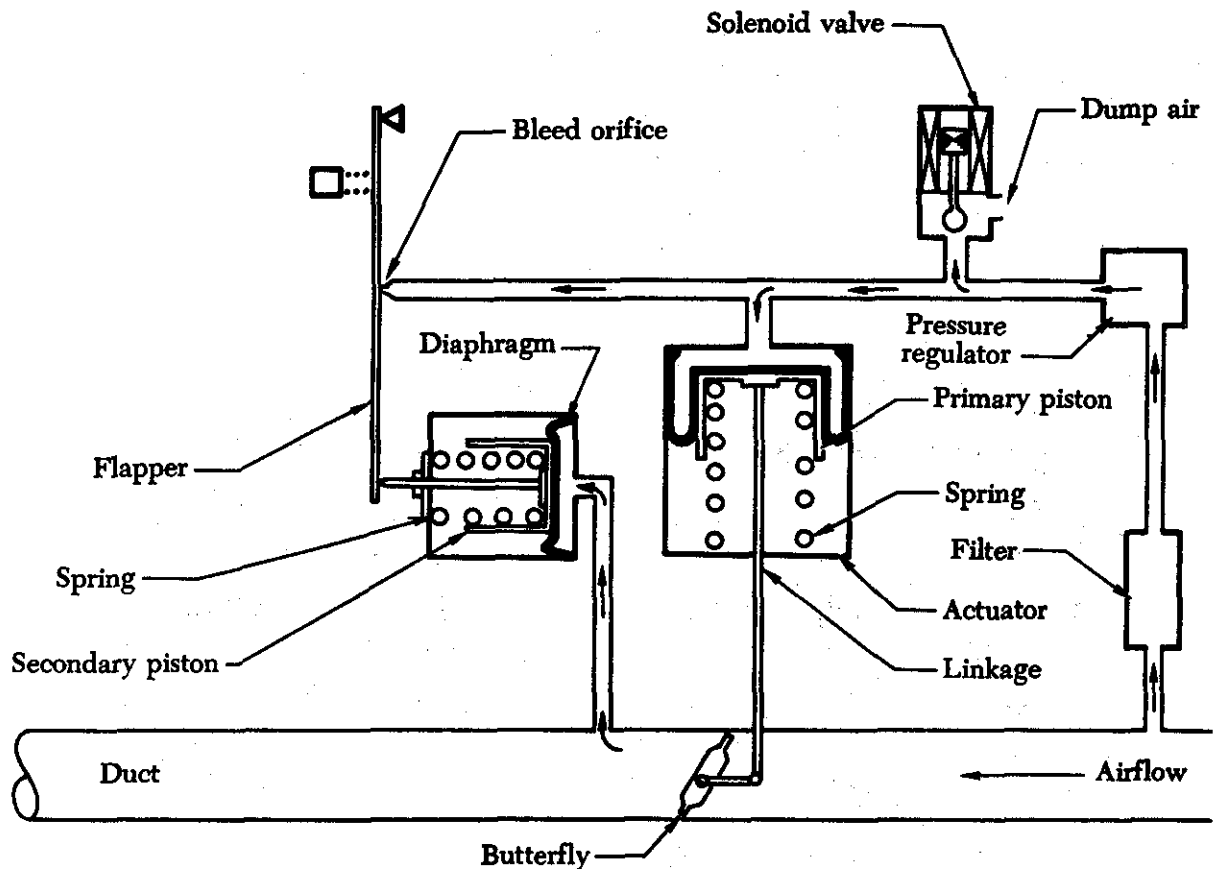


FIGURE 14-30. Shutoff valve.

shutoff valve for the cabin air conditioning and pressurization systems.

The valve requires electrical power and a minimum of 15 p.s.i. upstream pressure to function. It will regulate the downstream pressure to 115 p.s.i. Although this is an open/close valve, its major open function is to regulate. This is accomplished by a spring-loaded valve in the airflow line which is controlled by a primary piston. Upstream air pressure (if above 15 p.s.i.) bleeds through a filter and regulating mechanism to act on the primary piston, thereby opening the valve. After the downstream pressure rises to 115 p.s.i., it acts on a secondary piston which, through mechanical linkage, opens a bleed orifice to limit the amount of air acting on the primary piston. Since the primary piston is spring loaded to the "closed" position, it will then partially close, limiting the downstream pressure to 115 p.s.i.

The shutoff valve is operated by a solenoid valve that is spring loaded to off. In the "off" position, the control air from upstream is vented to atmosphere before it can operate the primary piston.

When the cockpit switch is actuated, the solenoid is energized and the vent closes, allowing pressure to build up to operate the primary piston.

Refrigeration Bypass Valve

The refrigeration bypass valve (figure 14-31) operates in conjunction with the temperature control system to modulate and control the flow of bypass air to the refrigeration unit. This action automatically maintains the cabin air at the temperature selected through the temperature controller. The valve is electrically controlled and pneumatically operated. Its operation relies on a signal from the downstream temperature-sensing element, which is controlled through the temperature control system, for an "open" position, but utilizes upstream pneumatic pressure to open the valve.

When electrical power is applied, a current-carrying coil and armature (transducer) is energized, closing a bleed port in the pressure chamber of the valve. The resulting pressure buildup in the chamber forces a piston to rotate a butterfly valve in the

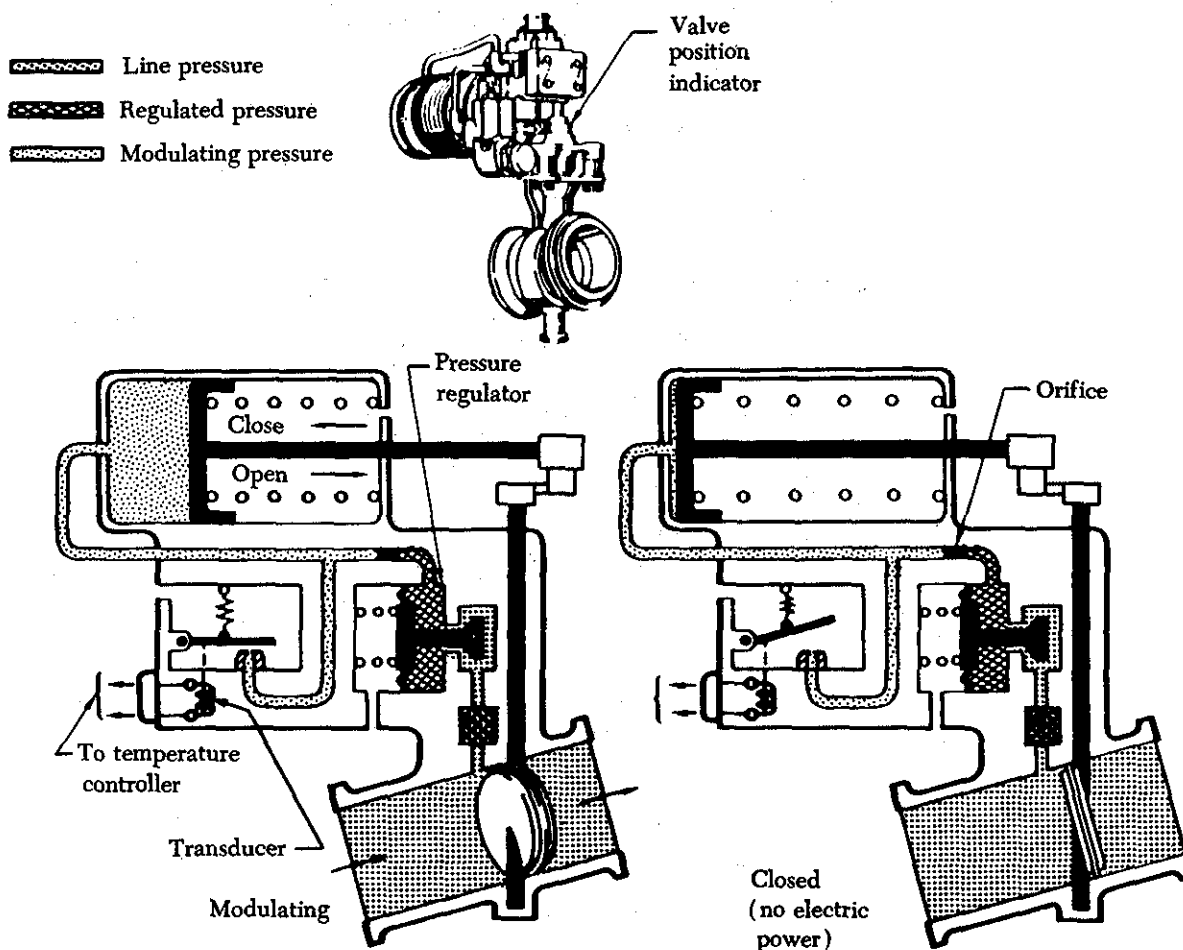


FIGURE 14-31. Refrigeration bypass valve.

cabin air duct to an "open" position. As the temperature varies or a new temperature is selected, the valve is re-positioned accordingly. Re-positioning is accomplished by action of the transducer in varying the amount of pressure allowed to bleed from the pressure chamber. Failure of the bypass valve or its components will cause the valve to move to the fail-safe (closed) position.

Secondary Heat Exchanger

The function of the secondary heat exchanger is to partially cool the air for cabin pressurization and air conditioning to a temperature which makes possible the efficient operation of the refrigeration unit.

The heat exchanger assembly consists mainly of dimpled aluminum alloy tubes. The tubes are arranged so that pressurized cabin air can flow through them and cooling air can flow across them.

The secondary heat exchanger operates in essentially the same manner as the primary heat exchanger.

Cabin air that is to be further cooled is routed through the tubes in the heat exchanger core. Cooling air is forced through the secondary heat exchanger and returned to an engine air inlet or can be exhausted directly to the atmosphere.

Cabin air is regulated by the refrigeration bypass valve where it is directed to the secondary heat exchanger or to the refrigeration unit bypass line in metered quantities as required to meet the demands of the temperature control system.

Refrigeration Unit

The refrigeration unit or turbine is used in the air conditioning system to cool the pressurized air for the cabin. Operation of the unit is entirely automatic, the power being derived from the pressure and temperature of the compressed air passing through the turbine wheel. The refrigeration cycle is modulated to meet varying cabin cooling demands by a refrigeration bypass valve which pro-

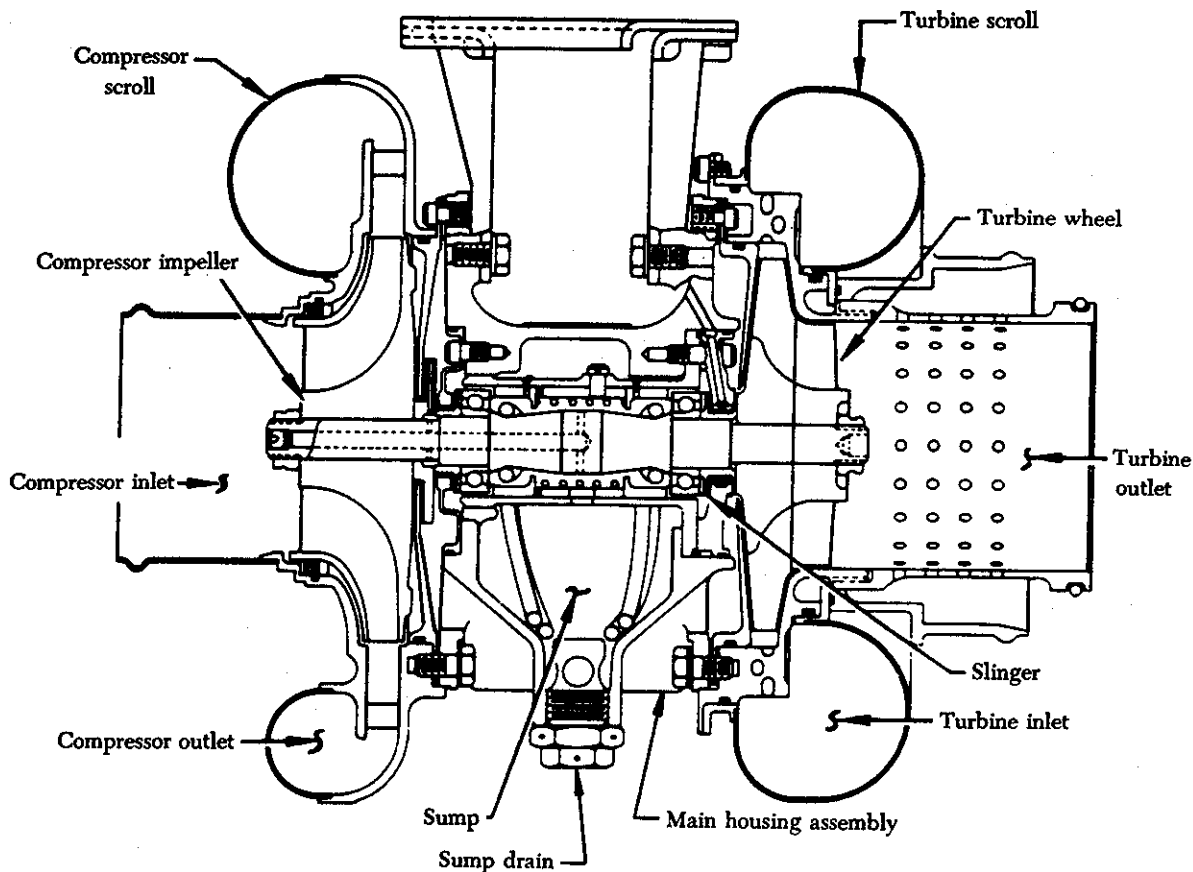


FIGURE 14-32. Schematic of a refrigeration turbine.

vides for a bypass of the entire refrigeration unit. Thus, cabin temperature is regulated by mixing bypassed air with that which has passed through the refrigeration unit.

The refrigeration turbine (figure 14-32) consists of three major sections: (1) Main housing assembly, (2) turbine scroll assembly, and (3) compressor scroll assembly.

The main housing assembly provides mounting for the two scroll assemblies and provides support for the two shaft bearings. It also serves as the oil reservoir from which the oil is supplied to the bearings by wicks. A dipstick for checking oil level is attached to the filler cap. The turbine scroll assembly is composed of two halves which confine the turbine nozzle within which the turbine wheel rotates. The compressor scroll assembly is composed of two halves which confine the diffuser within which the compressor wheel rotates.

A common shaft carries both assemblies and is supported by bearings in the housing assembly. An

oil slinger is mounted outboard of each of the bearings which carry the shaft. These slingers pump an oil/air mist through the bearings to provide for lubrication. Air/oil seals are provided between each slinger and the adjacent wheel.

The supply air which is being cooled drives the refrigeration turbine. An impeller, driven by this turbine, forces the cooling air through the refrigeration unit.

The refrigeration process takes place as the hot compressed air expands through the turbine wheel of the air expansion turbine. This results in a reduction in the temperature and pressure of the air. As this hot compressed air expands, it releases energy to the turbine wheel causing it to rotate at high speed.

Since the turbine wheel and compressor wheel are on opposite ends of a common shaft, the turbine wheel rotation results in a corresponding rotation of the compressor wheel. Thus, the energy released from the high temperature compressed air to the

turbine wheel provides the energy required by the compressor wheel to further compress the incoming air. The load imposed on the turbine by the compressor holds the speed of rotation within the range of maximum efficiency. Reduction of the air temperature assists in maintaining the cabin temperature within desired limits.

Water Separators

Water separators (figure 14-33) are used in the cabin air conditioning system to remove excessive moisture from the air. In most refrigeration systems a water separator is installed in the discharge duct of the cooling turbine.

The water separator removes excess moisture from the conditioned air by passing the air through a coalescent bag or condenser. Very small water particles in the form of fog or mist in the air are formed into larger particles in passing through the condenser. As the moisture laden air passes through the vanes of the coalescent support, the water particles are carried with the swirling air and are thrown outward against the walls of the collector.

The water then drains into a collector sump and is drained overboard.

Some water separators also contain a pressure-relief and altitude-sensitive bypass valve. Since very little moisture is present in the air at high altitudes, the bypass valve in the water separator opens at a predetermined altitude, generally 20,000 ft., to permit cold air to pass directly through the water separator, bypassing the coalescent bag and reducing system back pressure. The bypass valve will also open if, for some reason, the coalescent bag should become obstructed.

A coalescent bag condition indicator is provided on some water separators to indicate when the bag is dirty. The indicator senses a pressure drop across the bag and indicates when the pressure drop is excessive. Since the indicator is pressure sensitive, the condition of the bag can be determined only while the system is in operation.

Ram-Air Valve

The ram-air valve is always closed during normal operations. It is energized to open when the cockpit

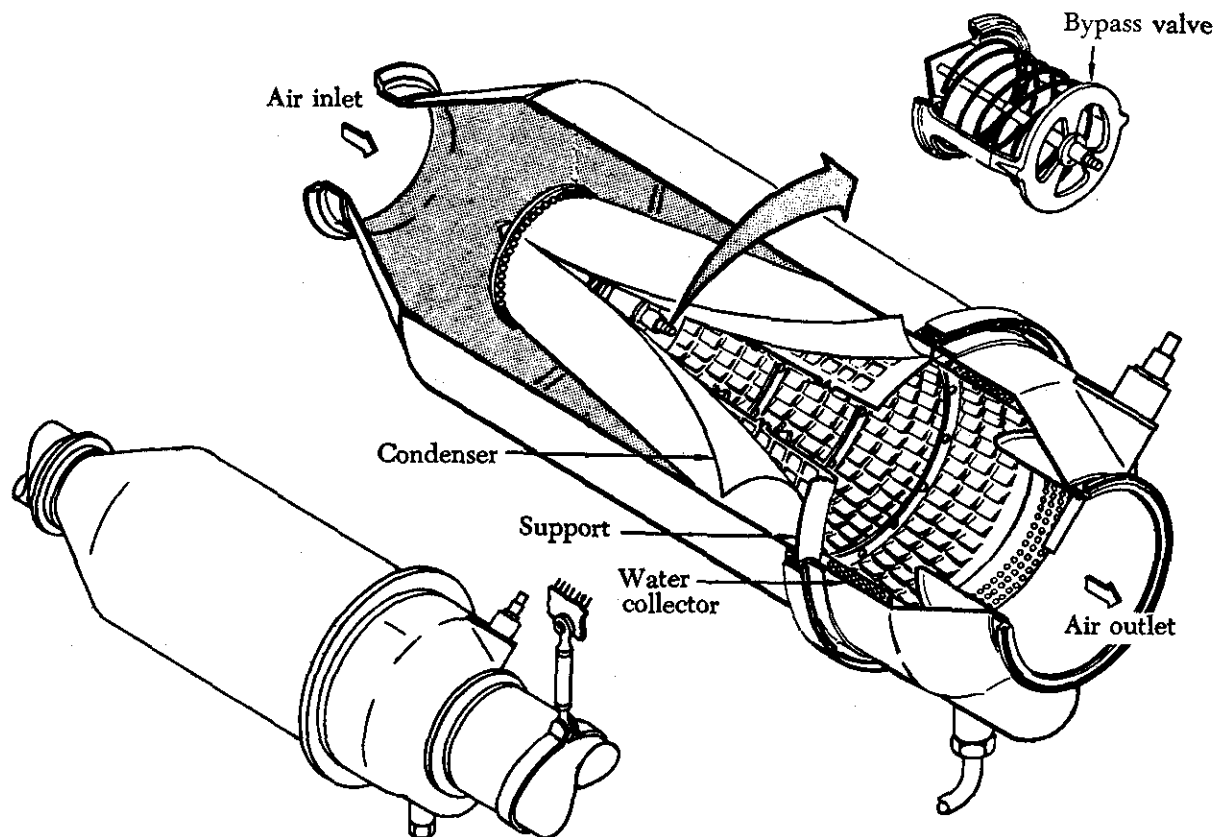


FIGURE 14-33. Water separator.

switch is placed in the "ram" position. With the ram-air valve open, air from the air inlet duct is admitted through the valve and directly into the cabin air supply duct.

ELECTRONIC CABIN TEMPERATURE CONTROL SYSTEM

The operation of the electronic temperature control system is based primarily on the balanced-bridge circuit principle. When any of the units which compose the "legs" of the bridge circuit change resistance value because of a temperature change, the bridge circuit becomes unbalanced. An electronic regulator receives an electrical signal as a result of this unbalance and amplifies this signal to control the mixing valve actuator.

In a typical application of the electronic temperature control system, three units are utilized: (1) Cabin temperature pickup (thermistor), (2) manual temperature selector, and (3) electronic regulator. Figure 14-34 shows a simplified schematic diagram of an electronic temperature control system.

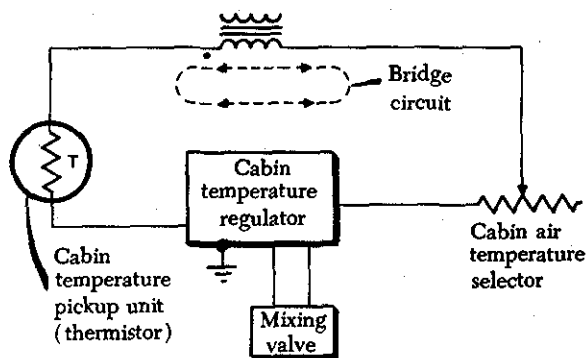


FIGURE 14-34. Electronic air temperature control system (simplified).

Cabin Temperature Pickup Unit

The cabin temperature pickup unit (temperature sensing unit) consists of a resistor that is highly sensitive to temperature changes. The temperature pickup unit is usually located in the cabin or cabin air supply duct. As the temperature of the air supply changes, the resistance value of the pickup unit also changes, thus causing the voltage drop across the pickup to change. The cabin temperature pickup is a thermistor type unit (figure 14-35). As the ambient temperature of the resistance bulb increases, the resistance of the bulb decreases.

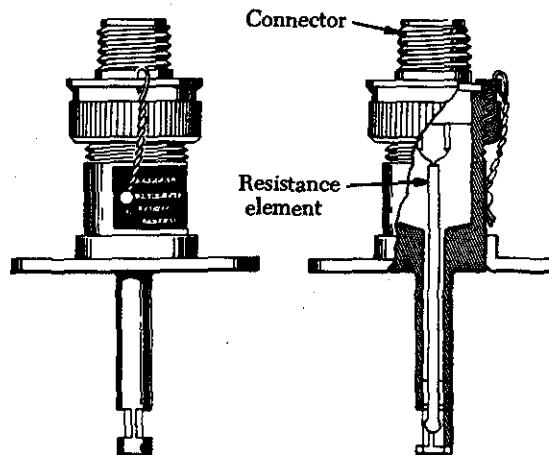


FIGURE 14-35. Thermistor.

Cabin Air Temperature Selector

The air temperature selector (see figure 14-34) is a rheostat located in the cabin. It permits selective temperature control by varying the effective temperature control point of the cabin air temperature pickup unit. The rheostat causes the cabin temperature pickup unit to demand a specific temperature of the supply air.

Cabin Air Temperature Control Regulator

The cabin air temperature control regulator, in conjunction with the air temperature selector rheostat and the air duct temperature pickup unit, automatically maintains the temperature of the air entering the cabin at a preselected value. The temperature regulator is an electronic device with a temperature regulating range. In some installations, this range may extend from as low as 32° F. to as high as 117° F.

The output of the regulator controls the position of the butterfly in the mixing valve, thus controlling the temperature of the inlet air to the cabin.

Typical System Operation

Figure 14-36 shows an electrical schematic of a typical air temperature control system. In most air temperature control systems, there is one switch to select the mode of temperature control. Usually, this switch will have four positions: "off," "auto," "man. hot," and "man. cold." In the "off" position, the air temperature control system is inoperative. With the switch in the "auto" range, the air temperature control system is in the automatic mode. With the switch in either the "man. hot" or "man. cold" position, the air temperature control system is in the manual mode.

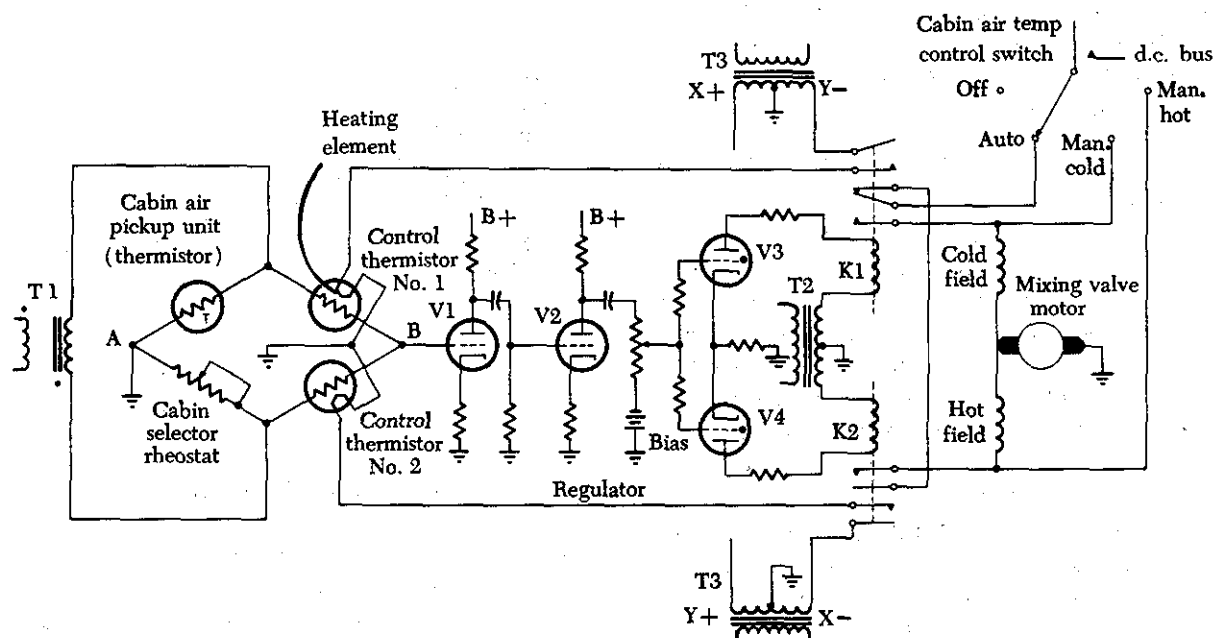


FIGURE 14-36. Air temperature control system (simplified).

ELECTRONIC TEMPERATURE CONTROL REGULATOR

The cabin selector rheostat and the cabin air pickup unit (thermistor) determine the direction and amount of rotation of the mixing valve motor. This function is controlled in the cabin air temperature regulator. The cabin selector rheostat and the cabin air pickup unit (see figure 14-36) are connected into a bridge circuit which also includes two thermistors that are located in the regulator.

The bridge circuit is energized by an a.c. source (T1). If the resistance of the cabin air pickup unit and the cabin selector rheostat were equal, then points A and B would have no potential difference.

Note that points A and B are the signal reference points for V1 (grid and cathode). If the cabin air temperature increases, the resistance value of the cabin air temperature pickup unit decreases, since the flow of the air passes over the pickup unit. This decrease in resistance of the pickup unit causes the voltage developed across the pickup unit to decrease, resulting in a potential difference between points A and B.

This signal, which is impressed on the grid of V1, goes through two stages of voltage amplification (V1 and V2). The amplified signal is applied to the grids of the two thyatron tubes (V3 and V4). The thyatron tubes (gas filled triode or te-

trode) are used for signal phase detection. For example, if the signal on the grid of V3 is in phase with the signal on the plate, V3 will conduct, causing current to flow through the coil of relay K1 and close its contacts.

One set of contacts completes a circuit for direct current flow to the cold-field coil of the mixing valve motor. This directs more hot air into the refrigeration unit, thereby cooling the cabin air.

At the same time, the remaining set of contacts of K1 completes a source of a.c. power (T3) to the heating element of thermistor No. 1 of the bridge circuit, causing the resistance of thermistor No. 1 to decrease. (Remember that a thermistor's resistance decreases as the temperature rises.) The resultant change in the voltage drop across thermistor No. 1 results in a balanced bridge across points A and B. This, in turn, causes relay K1 to become de-energized, stopping the rotation of the mixing valve motor.

At this point, heater voltage is removed from thermistor No. 1 and it cools, again unbalancing the bridge. This causes the mixing valve motor to drive farther towards the cool position, allowing still more refrigerated air to enter the cabin. Cycling continues until the drops in voltage across the pickup unit and the selector rheostat are equal.

Had the cabin air temperature been colder than the selected setting, the bridge would have become

unbalanced in the opposite direction. This would have caused relay K2 on the regulator to become energized, thus energizing the hot-field coil of the mixing valve motor.

The bridge may also be unbalanced by another method, *i.e.*, by re-positioning the cabin selector rheostat. Again the mixing valve moves to regulate the temperature of the air until the bridge is re-balanced.

VAPOR CYCLE SYSTEM (FREON)

Vapor cycle cooling systems are used on several large transport aircraft. This system usually has a greater cooling capacity than an air cycle system, and in addition, can usually be used for cooling on the ground when the engines are not operating.

An aircraft freon system is basically similar in principle to the kitchen refrigerator or the home air conditioner. It uses similar components and operating principles and in most cases depends upon the electrical system for power.

Vapor cycle systems make use of the scientific fact that a liquid can be vaporized at any temperature by changing the pressure acting on it. Water, at sea level barometric pressure of 14.7 p.s.i.a. will boil if its temperature is raised to 212° F. The same water in a closed tank under a pressure of 90 p.s.i.a. will not boil at less than 320° F. If the pressure is reduced to 0.95 p.s.i.a. by a vacuum pump, the water will boil at 100° F. If the pressure is reduced further, the water will boil at a still lower temperature; for instance, at 0.12 p.s.i.a., water will boil at 40° F. Water can be made to boil at any temperature if the pressure corresponding to the desired boiling temperature can be maintained.

Refrigeration Cycle

The basic laws of thermodynamics state that heat will flow from a point of higher temperature to a point of lower temperature. If heat is to be made to flow in the opposite direction, some energy must be supplied. The method used to accomplish this in an air conditioner is based on the fact that when a gas is compressed, its temperature is raised, and, similarly, when a compressed gas is allowed to expand, its temperature is lowered.

To achieve the required "reverse" flow of heat, a gas is compressed to a pressure high enough so that its temperature is raised above that of the outside air. Heat will now flow from the higher temperature gas to the lower temperature surrounding air (heat sink), thus lowering the heat content of the gas.

The gas is now allowed to expand to a lower pressure; this causes a drop in temperature that makes it cooler than the air in the space to be cooled (heat source).

Heat will now flow from the heat source to the gas, which is then compressed again, beginning a new cycle. The mechanical energy required to cause this apparent reverse flow of heat is supplied by a compressor. A typical refrigeration cycle is illustrated in figure 14-37.

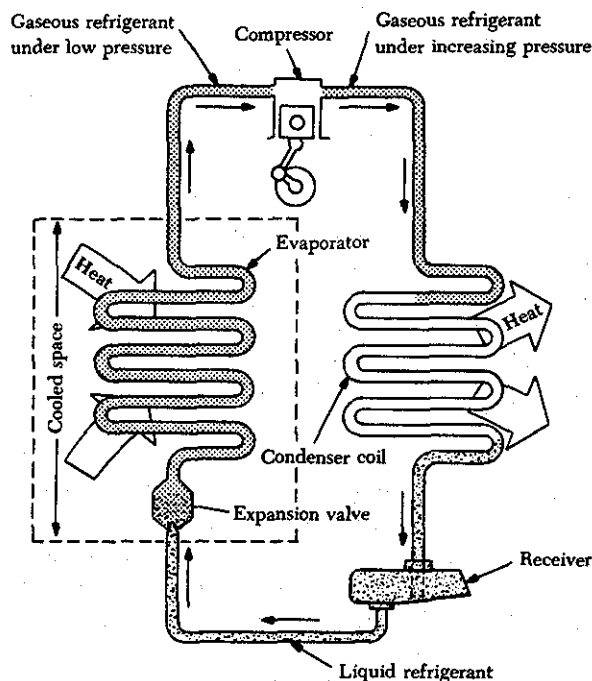


FIGURE 14-37. Refrigeration cycle.

This refrigeration cycle is based on the principle that the boiling point of a liquid is raised when the pressure of the vapor around the liquid is raised. The cycle operates as follows: A liquid refrigerant confined in the receiver at a high pressure is allowed to flow through the expansion valve into the evaporator. The pressure in the evaporator is low enough so that the boiling point of the liquid refrigerant is below the temperature of the air to be cooled, or heat source. Heat flows from the space to be cooled to the liquid refrigerant, causing it to boil (to be converted from liquid to a vapor). Cold vapor from the evaporator enters the compressor, where its pressure is raised, thereby raising the boiling point. The refrigerant at a high pressure and high temperature flows into the condenser.

Here heat flows from the refrigerant to the outside air, condensing the vapor into a liquid. The cycle is repeated to maintain the cooled space at the selected temperature.

Liquids that will boil at low temperatures are the most desirable for use as refrigerants. Comparatively large quantities of heat are absorbed when liquids are changed to a vapor. For this reason, liquid freon is used in most vapor cycle refrigeration units whether used in aircraft or in home air conditioners and refrigerators.

Freon is a fluid which boils at a temperature of approximately 39° F. under atmospheric pressure. Similar to other fluids, the boiling point may be raised to approximately 150° F. under a pressure of 96 p.s.i.g. These pressures and temperatures are representative of one type of freon. Actual values will vary slightly with different types of freon. The type of freon selected for a particular aircraft will depend upon the design of the freon system components installed.

Freon, similar to other fluids, has the characteristic of absorbing heat when it changes from a liquid to a vapor. Conversely, the fluid releases heat when it changes from a vapor to a liquid. In the freon cooling system, the change from liquid to vapor (evaporation or boiling) takes place at a location where heat can be absorbed from the cabin air, and the change from vapor to liquid (condensation) takes place at a point where the released heat can be ejected to the outside of the aircraft. The pressure of the vapor is raised prior to the condensation process so that the condensation temperature is relatively high. Therefore, the freon, condensing at approximately 150° F., will lose heat to the outside air which may be as hot as 100° F.

The quantity of heat that each pound of refrigerant liquid absorbs while flowing through the evaporator is known as the "refrigeration effect." Each pound flowing through the evaporator is able to absorb only the heat needed to vaporize it, if no superheating (raising the temperature of a gas above that of the boiling point of its liquid state) takes place. If the liquid approaching the expansion valve were at exactly the temperature at which it was vaporizing in the evaporator, the quantity of heat that the refrigerant could absorb would be equal to its latent heat. That is the amount of heat required to change the state of a liquid, at the boiling point, to a gas at the same temperature.

When liquid refrigerant is admitted to the evaporator, it is completely vaporized before it reaches

the outlet. Since the liquid is vaporized at a low temperature, the vapor is still cold after the liquid has completely evaporated. As the cold vapor flows through the balance of the evaporator, it continues to absorb heat and becomes superheated.

The vapor absorbs sensible heat (heat which causes a temperature change when added to, or removed from matter) in the evaporator as it becomes superheated. This, in effect, increases the refrigerating effect of each pound of refrigerant. This means that each pound of refrigerant absorbs not only the heat required to vaporize it, but also an additional amount of sensible heat which superheats it.

FREON SYSTEM COMPONENTS

The major components of a typical freon system are the evaporator, compressor, condenser, and expansion valve (figure 14-38). Other minor items may include the condenser fan, receiver (freon storage), dryer, surge valve, and temperature controls. These items are interconnected by appropriate tubing to form a closed loop in which the freon is circulated during operation.

Freon System Operational Cycle Compressor

The principle of operation of the system can be explained by starting with the function of the compressor. The compressor increases the pressure of the freon when it is in vapor form. This high pressure raises the condensation temperature of the freon and produces the force necessary to circulate the freon through the system.

The compressor is driven either by an electric motor or by an air turbine drive mechanism. The compressor may be a centrifugal type or a piston type. The compressor is designed to act upon freon in a gaseous state and in conjunction with the expansion valve, maintains a difference in pressure between the evaporator and the condenser. If the liquid refrigerant were to enter the compressor, improper operation would occur. This type of malfunction is called "slugging." Automatic controls and proper operating procedures must be used to prevent slugging.

Condenser

The freon gas is pumped to the condenser for the next step in the cycle. At the condenser the gas passes through a heat exchanger where outside (ambient) air removes heat from the freon. When heat is removed from the high-pressure freon gas, a change of state takes place and the freon condenses to a liquid. It is this condensation process which releases the heat the freon picks up from

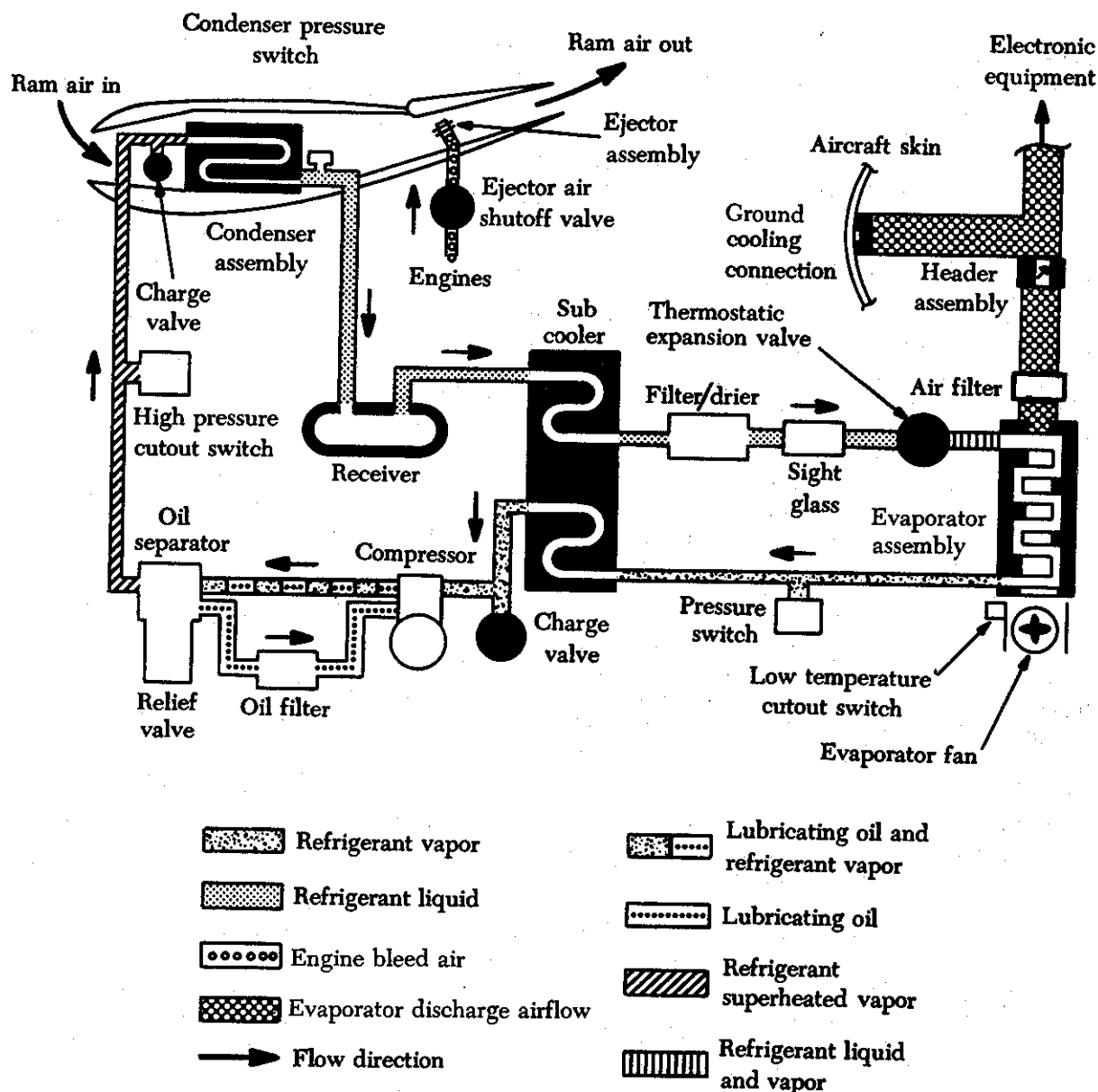


FIGURE 14-38. Vapor cycle system flow schematic.

the cabin air. The flow of ambient air through the condenser unit is ordinarily modulated by controllable inlet or outlet doors according to cooling requirements. A condenser cooling air fan or air ejector is often used to help force the ambient air through the condenser; this item is important for operation of the system on the ground.

Receiver

From the condenser the liquid freon flows to the receiver which acts as a reservoir for the liquid refrigerant. The fluid level in the receiver varies with system demands. During peak cooling periods, there will be less liquid than when the load is light. The prime function of the receiver

is to ensure that the thermostatic expansion valve is not starved for refrigerant under heavy cooling load conditions.

Subcooler

Some vapor cycle systems use a subcooler to reduce the temperature of the liquid refrigerant after it leaves the receiver. By cooling the refrigerant premature vaporization (flash-off) can be prevented. Maximum cooling takes place when the refrigerant changes from a liquid to a gaseous state. For efficient system operation this must occur in the evaporator. If the refrigerant vaporizes before it reaches the evaporator the cooling efficiency of the system is reduced.

The subcooler is a heat exchanger containing passages for liquid freon from the receiver on its way to the evaporator and cold freon gas leaving the evaporator on its way to the compressor. The liquid on the way to the evaporator is relatively warm in comparison to the cold gas leaving the evaporator. Although the gas leaving the evaporator has absorbed heat from the air being circulated through the evaporator, its temperature is still in the vicinity of 40° F. This cool gas is fed through the subcooler where it picks up additional heat from the relatively warm liquid freon that is flowing from the receiver. This heat exchange subcools the liquid freon to a level that ensures little or no flash-off (premature vaporization) on its way to the evaporator.

Subcooling is a term used to describe the cooling of a liquid refrigerant at constant pressure to a point below the temperature at which it was condensed. At 117 p.s.i.g., freon vapor condenses at a temperature of 100° F. If, after the vapor has been completely condensed, the liquid is cooled still further to a temperature of 76° F., it will have been subcooled 24°. Through subcooling, the liquid delivered to the expansion valve is cool enough to prevent most of the flash-off that would normally result, thereby making the system more efficient.

Filter/Drier

The system illustrated in figure 14-38 has a filter/drier unit installed between the subcooler and the sight glass. The filter/drier is essentially a sheet-metal housing with inlet and outlet connections and contains alumina desiccant, a filter screen, and a filter pad. The alumina desiccant acts as a moisture absorbent so that dry freon flows to the expansion valve. A conical screen and fiber glass pad act as a filtering device, removing contaminants.

Scrupulously clean refrigerant at the expansion valve is a must because of the critical clearances involved. Moisture may freeze at the expansion valve, causing it to hang up with a resulting starvation or flooding of the evaporator.

Sight Glass

To aid in determining whether servicing of the refrigerating unit is required, a liquid line sight glass or liquid level gage is installed in the line between the filter/drier and the thermostatic expansion valve. The sight glass consists of a fitting with windows on both sides, permitting a view of fluid passage through the line. In some systems the sight glass is constructed as a part of the filter/drier.

During refrigeration unit operation, a steady flow of freon refrigerant observed through the sight glass indicates that sufficient charge is present. If the unit requires additional refrigerant, bubbles will be present in the sight glass.

Expansion Valve

The liquid freon flows to the expansion valve for the next step in the operation. The freon coming out of the condenser is high-pressure liquid refrigerant. The expansion valve lowers the freon pressure and thus lowers the temperature of the liquid freon. The cooler liquid freon makes it possible to cool cabin air passing through the evaporator.

The expansion valve, mounted close to the evaporator, meters the flow of refrigerant into the evaporator. Efficient evaporator operation depends upon the precise metering of liquid refrigerant into the heat exchanger for evaporation. If heat loads on the evaporator were constant, an orifice size could be calculated and used to regulate the refrigerant supply. A practical system, however, encounters varying heat loads and, therefore, requires a refrigerant throttling device to prevent starvation or flooding of the evaporator, which would affect the evaporator and system efficiency. This variable-orifice effect is accomplished by the thermostatic expansion valve, which senses evaporator conditions and meters refrigerant to satisfy them. By sensing the temperature and the pressure of the gas leaving the evaporator, the expansion valve precludes the possibility of flooding the evaporator and returning liquid refrigerant to the compressor.

The expansion valve, schematically portrayed in figure 14-39, consists of a housing containing inlet and outlet ports. The flow of refrigerant to the outlet ports is controlled by positioning a metering valve pin. Valve pin positioning is controlled by the pressure created by the remote sensing bulb, the superheat spring setting, and the evaporator discharge pressure supplied through the external equalizer port.

The remote sensing bulb is a closed system filled with refrigerant and the bulb is attached to the evaporator. Pressure within the bulb corresponds to the refrigerant pressure leaving the evaporator. This force is felt on top of the diaphragm in the power head section of the valve, and any increase in pressure will cause the valve to move towards an "open" position. The bottom side of the diaphragm has the forces of the superheat spring and evaporator discharge pressure acting in a direction to close the valve pin. The valve position at any instant is the result of these three forces.

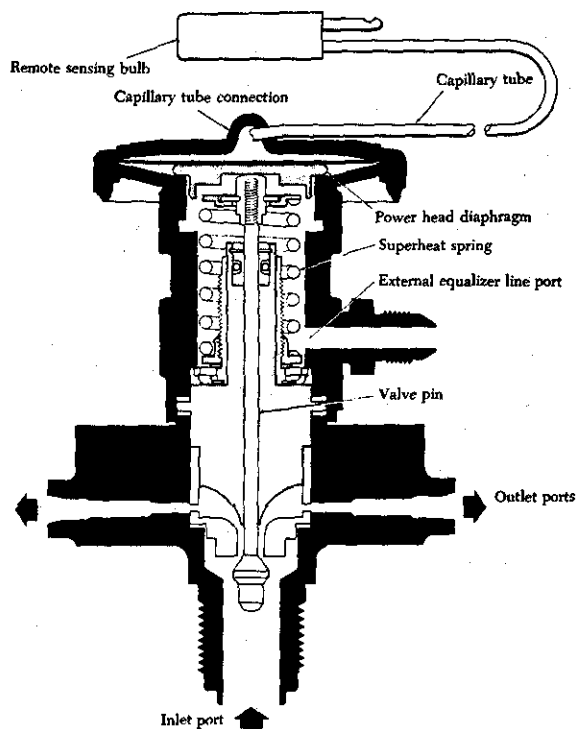


FIGURE 14-39. Schematic of thermostatic expansion valve.

If the temperature of the gas leaving the evaporator increases above the desired superheat valve, it will be sensed by the remote bulb. The pressure generated in the bulb is transmitted to the diaphragm in the power section of the valve, causing the valve pin to open. A decrease in the temperature of the gas leaving the evaporator will cause the pressure in the remote bulb to decrease, and the valve pin will move toward the "closed" position.

The superheat spring is designed to control the amount of superheat in the gas leaving the evaporator. A vapor is said to be superheated when its temperature is higher than that necessary to change it from a liquid to a gas at a certain pressure. This ensures that the freon returning to the compressor is in the gaseous state.

The equalizer port is provided to compensate for the effect the inherent evaporator pressure drop has on the superheat setting. The equalizer senses evaporator discharge pressure and reflects it back to the power head diaphragm, adjusting the expansion valve pin position to hold the desired superheat value.

Evaporator

The next unit in the line of cooling flow after the expansion valve is the evaporator, which is a heat exchanger forming passages for cooling air

flow and for freon refrigerant. Air to be cooled flows through the evaporator.

The freon changes from a liquid to a vapor at the evaporator. In effect, the freon boils in the evaporator, and the pressure of the freon is controlled to the point where the boiling (evaporation) takes place at a temperature which is lower than the cabin air temperature. The pressure (saturated pressure) necessary to produce the correct boiling temperature must not be too low; otherwise, freezing of the moisture in the cabin air will block the air passages of the evaporator. As the freon passes through the evaporator, it is entirely converted to the gaseous state.

This is essential to obtain the maximum cooling and also to prevent liquid freon from reaching the compressor. The evaporator is designed so that heat is taken from the cabin air; therefore, the cabin air is cooled. All the other components in the freon system are designed to support the evaporator, where the actual cooling is done.

After leaving the evaporator, the vaporized refrigerant flows to the compressor and is compressed. Heat is being withdrawn through the walls of the condenser and carried away by air circulating around the outside of the condenser. As the vapor condenses to a liquid it gives up the heat which was absorbed when the liquid changed to a vapor in the evaporator. From the condenser the liquid refrigerant flows back to the receiver, and the cycle is repeated.

DESCRIPTION OF A TYPICAL SYSTEM

Since the vapor cycle system used in Boeing aircraft models 707 and 720 are typical of most vapor cycle systems, they are used here to describe the operation of such systems.

The major components of the vapor cycle air conditioning system are the: (1) Air turbine centrifugal compressors, (2) primary heat exchangers, (3) refrigeration units, (4) heaters, and (5) necessary valves to control the airflow.

The vapor cycle system shown schematically in figure 14-40 is divided into a left-hand and a right-hand installation. Both installations are functionally identical.

Air Turbine Compressor

The cabin and flight compartments are pressurized by using two air turbine centrifugal compressors (turbo-compressors). Each compressor consists of a turbine section and a compressor section as shown in figure 14-41.

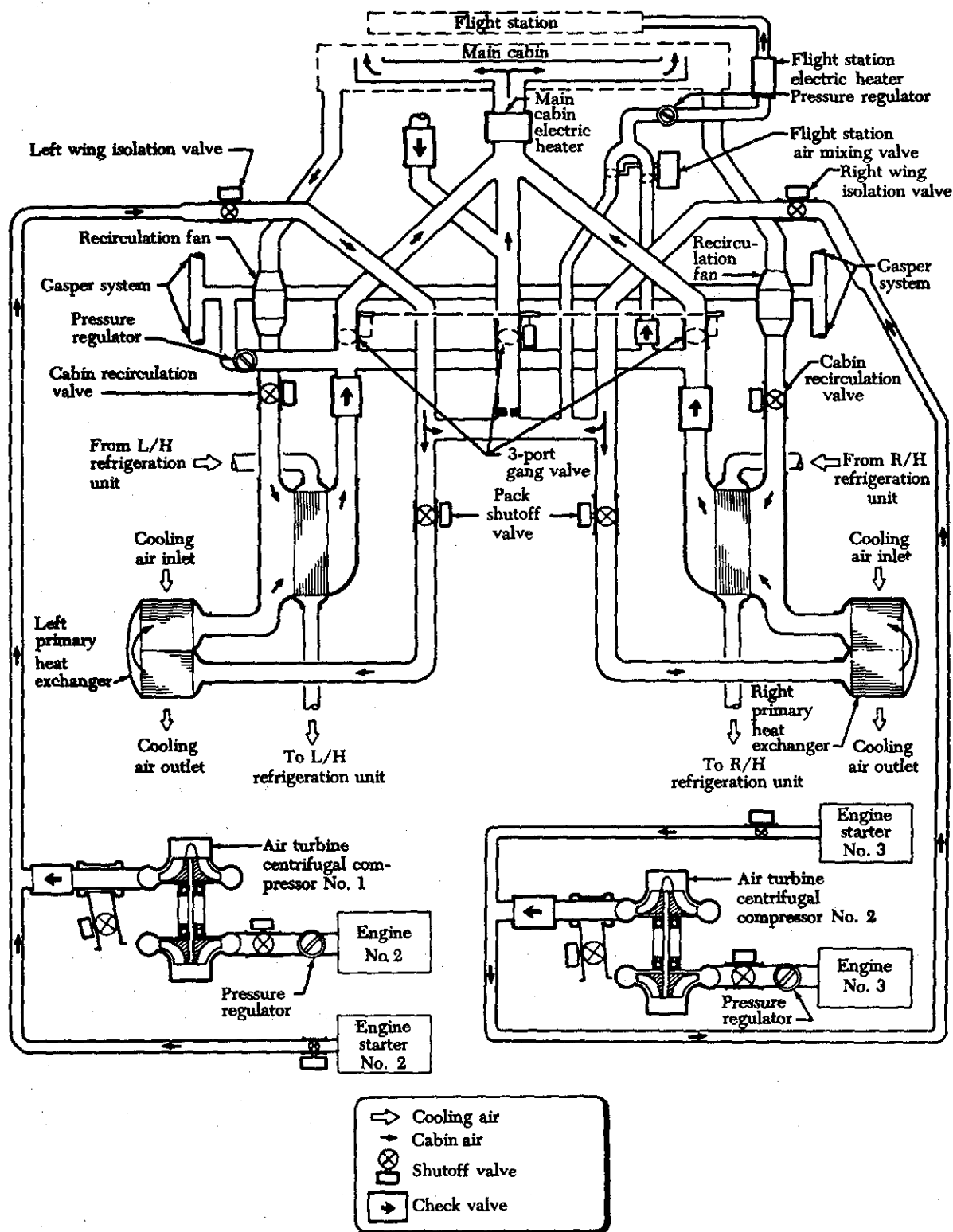


FIGURE 14-40. Schematic of vapor cycle air conditioning system on Boeing 707 and 720 airplanes.

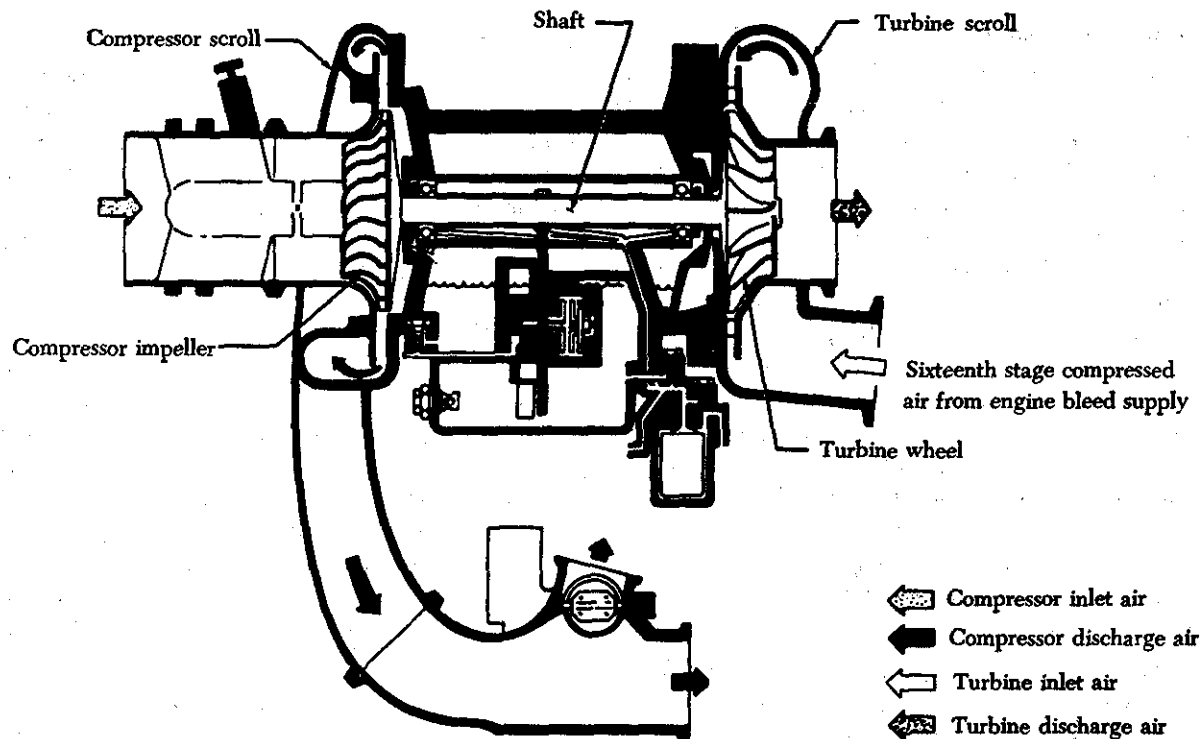


FIGURE 14-41. Schematic of air turbine centrifugal compressor.

The turbine section inlet duct is connected to the sixteenth stage compressed air from the engine bleed air manifold. The bleed air is under a pressure of approximately 170 p.s.i. This high-pressure, high-velocity air is reduced to approximately 76 p.s.i. by a differential pressure regulator located in the air duct leading to the turbine inlet. This regulated air pressure turns the turbine at about 49,000 r.p.m.

Since the compressor is connected directly to the turbine, it also turns at the same r.p.m. The compressor output is approximately 1,070 cu. ft. of air per minute at a maximum of 50 p.s.i. The compressor section inlet is connected to a ram-air scoop and the outlet is connected through ducts into the air conditioning system.

Air flows through the ducts, through a wing isolation valve, past the shutoff valve, and through the primary heat exchanger.

Primary Heat Exchangers

The two primary (air-to-air) heat exchangers are located in the left- and right-hand installation of the vapor cycle system as shown in figure 14-40.

Each primary heat exchanger consists of a duct assembly, a core assembly, and a pan assembly. The welded duct assembly contains both the inlet and outlet passages. The tube-type core assembly forms

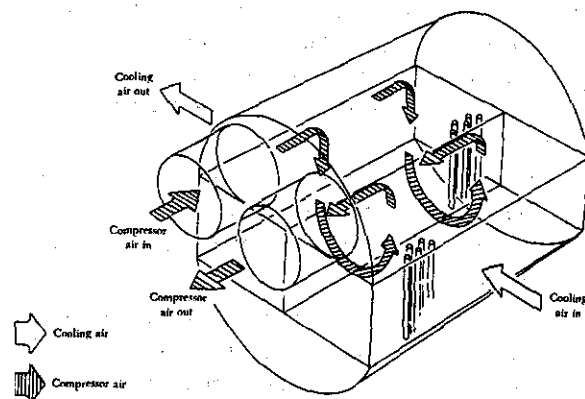


FIGURE 14-42. Schematic of primary heat exchanger.

the center portion of the unit. The pan assembly completes the enclosure of the tubes. Cabin ventilating air flows through the inside of the tubes of the core assembly. Ram air is forced around and between the outside of the tubes. Figure 14-42 shows a schematic diagram of the primary heat exchanger.

The primary heat exchangers remove about 10% of the heat of compression from the cabin ventilating air as it comes from the turbo-compressors, thus cooling the air to about 10° to 25° above outside air temperature.

Refrigeration Units

From the primary heat exchangers the ventilating air is ducted to the refrigeration units. The two refrigeration units are located in the left- and right-hand installation of the vapor cycle system as shown in figure 14-40. Each refrigeration unit consists of an electric motor driven freon compressor, an air-cooled refrigerant condenser, a receiver (freon container), an evaporator heat exchanger, a dual control valve, a heat exchanger (liquid-to-gas), and the necessary electrical components to assure proper operation of the unit. The refrigerant used in the system is freon 114. Lubricating oil is added to the freon each time the refrigeration unit is charged to provide lubrication for the compressor bearings.

After the air is cooled to the desired temperature, it is ducted into the cabin and flight deck.

Electric Heaters

The main cabin ventilating air and the flight compartment ventilating air are heated separately and independently by two electric heaters, one heater for each.

The flight compartment heater consists of a core which is made up of nine electrical heater elements mounted in a rectangular aluminum shell assembly, three protectors, a.c. power connection to the elements, and a control circuit to the thermal protectors.

The main cabin heater is similar but has a greater output capacity since it provides heat for a larger compartment and a greater volume of air.

Air Routing/Valves

The solid black arrows in figure 14-40 indicate the flow route of the ventilating air from the turbo-compressor, through the air conditioning units to the cabin and flight compartment. The three-port gang valve regulates the flow of hot or cold air to the cabin in response to the selected temperature.

AIR CONDITIONING AND PRESSURIZATION SYSTEM MAINTENANCE

The maintenance required on air conditioning and pressurization systems varies with each aircraft model. This maintenance follows procedures given in the appropriate aircraft manufacturer or equipment manufacturer's maintenance manuals. It usually consists of inspections, servicing, removing, and installing components, performing operational checks, and troubleshooting for the isolation and correction of troubles within the system.

Inspections

Periodically inspect the system for component security and visible defects. Particular attention should be paid to the heat exchangers for signs of structural fatigue adjacent to welds. The ducting should be securely attached and adequately supported. Insulating blankets must be in good repair and secured around the ducting.

Servicing

Each refrigeration unit contains freon for absorbing heat, plus oil mixed with the freon for lubricating the compressor motor bearings. If there is insufficient freon in the unit, it is incapable of absorbing heat from the air going to the cabin. If there is insufficient oil, the motor bearings will overheat and eventually cause unsatisfactory compressor operation. It is important that sufficient amounts of freon and oil be in the unit at all times.

In contrast to a hydraulic system where the circuits consist of closed loops containing fluid at all times, a freon loop contains quantities of both liquid and vapor. This, in addition to the fact that it is unpredictable exactly where in the system the liquid will be at any one instant, makes it difficult to check the quantity of freon in the system.

Regardless of the amount of freon in the complete system, the liquid level can vary significantly, depending on the operating conditions. For this reason, a standard set of conditions should be obtained when checking the freon level. These conditions are specified by the manufacturer and, as mentioned previously, vary from aircraft to aircraft.

To check the freon level, it is necessary to operate the refrigeration unit for approximately 5 min. to reach a stable condition. If the system uses a sight glass, observe the flow of freon through the sight glass. A steady flow indicates that a sufficient charge is present. If the freon charge is low, bubbles will appear in the sight glass.

When adding freon to a system, add as much oil as is felt was lost with the freon being replaced. It is impossible to determine accurately the amount of oil left in a freon system after partial or complete loss of the freon charge. However, based on experience, most manufacturers have established procedures for adding oil. The amount of oil to be added is governed by: (1) The amount of freon to be added, (2) whether the system has lost all of its charge and has been purged and evacuated, (3) whether a topping charge is to be added, or (4)

whether major components of the system have been changed.

Usually one-fourth-ounce of oil is added for each pound of freon added to the system. When changing a component, an additional amount of oil is added to replace that which is trapped in the replaced component.

Oil for lubrication of the compressor expansion valve, and associated seals must be sealed in the system. The oil used is a special highly refined mineral oil free from wax, water and sulfur. Always use the oil specified in the manufacturer's maintenance manual for a specific system.

Freon-12

Freon-12 is the most commonly used refrigerant. It is a fluorinated hydrocarbon similar to carbon tetrachloride with 2 of the chlorine atoms replaced by 2 fluorine atoms. It is stable at low or high temperatures, does not react with any of the materials or seals used in an air conditioning system, and is non-flammable.

Freon-12 will boil at sea level pressure at -21.6° F. Any freon-12 dropped on the skin will result in frostbite. Even a trace in the eye can cause damage. If this should occur, treat the eye with clean mineral oil, or petroleum jelly followed with a boric acid wash. *GET TO A PHYSICIAN OR HOSPITAL AS SOON AS POSSIBLE.*

Freon is colorless, odorless, and non-toxic; however, being heavier than air, it will displace oxygen and can cause suffocation. When heated over an open flame, it converts to phosgene gas which is deadly! Avoid inhaling freon or contact with this gas.

Wear a face shield, gloves and protective clothing when working with freon.

Manifold Set

Whenever a freon system is opened for maintenance, a portion of the freon and oil will be lost. Replenishment of the freon and oil is a must for efficient system operation. This requires the use of a special set of gages and interconnected hoses.

The manifold set (figure 14-43) consists of a manifold with three fittings to which refrigerant service hoses are attached: two hand valves with "O" ring type seals, two gages, one for the low pressure side of the system and one for the high pressure side of the system.

The low pressure gage is a compound gage, meaning it will read pressures either side of atmospheric. It will indicate to about 30 inches of mercury, gage pressure (below atmospheric) to about 60 psi gage pressure above atmospheric.

The high pressure gages usually have a range from zero up to about 600 p.s.i. gage pressure.

The low pressure gage is connected on the manifold directly to the low side fitting. The high pressure gage likewise connects directly to the high side fitting. The center fitting of the manifold can be isolated from either of the gages or the high and low service fittings by the hand valves. When these valves are turned fully clockwise, the center fitting is isolated. If the low pressure valve is opened (turned counter-clockwise), the center fitting is opened to the low pressure gage and the low side service line. The same is true for the high side when the high pressure valve is opened.

Special hoses are attached to the fittings of the manifold valve for servicing the system. The high pressure charging hose attaches to the service valve in the high side, either at the compressor discharge, the receiver dryer, or on the inlet side of the expansion valve. The low pressure hose attaches to

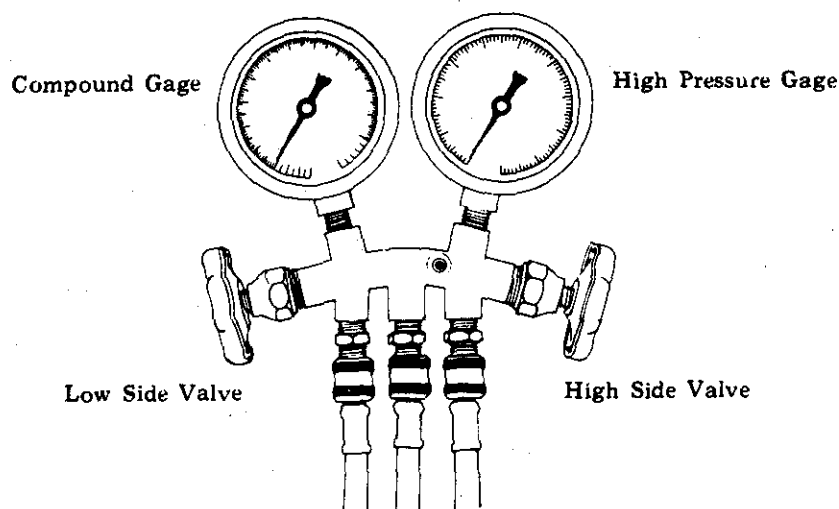


FIGURE 14-43. Freon manifold set.

the service valve at the compressor inlet, or at the discharge side of the expansion valve. The center hose attaches to the vacuum pump for evacuating the system, or to the refrigerant supply for charging the system. Charging hoses used with Schrader valves must have a pin to depress the valve.

When not using the manifold set, be sure the hoses are capped to prevent moisture contaminating the valves.

Purging the System

Whenever a freon system is to be opened for maintenance it is necessary to purge the system. The manifold set is connected as previously described except the center hose is not yet connected to the vacuum pump. Cover the center hose with a clean shop towel, open both valves slowly. This will permit the gas to escape but will not blow the oil from the system. When both gages read zero, the system may be opened.

Evacuating the System

Only a few drops of moisture will contaminate and completely block an air conditioning system. If this moisture freezes in the expansion valve, the action stops. Water is removed from the system by evacuation. Anytime the system has been opened it must be evacuated before recharging.

The manifold set is connected into the system with the center hose connected to a vacuum pump. The pump reduces the pressure, moisture vaporizes and is drawn from the system. A typical pump used for evacuating air conditioning systems will pump 0.8 cubic feet of air per minute and will evacuate the system to about 29.62 inches of mercury (gage pressure). At this pressure water will boil at 45° F. Pumping down or evacuating a system usually requires about 60 minutes pumping time.

Recharging

With the system under vacuum from evacuation, close all valves, connect the center hose to a refrigerant supply. Open the container valve, loosen the high side hose at its connection to the system, and allow some freon to escape. This purges the manifold set. Tighten the hose.

Open the high pressure valve, this will permit freon to flow into the system. The low pressure gage should begin to indicate that the system is coming out of the vacuum. Close both valves. Start the engine, set the rpm at about 1250. Set the controls for full cooling. With the freon container upright to allow vapor to come out, open

the low pressure valve to allow vapors to enter the system. Put as many pounds of freon into the system as called for by the specifications. Close all valves, remove manifold set and perform an operational check.

Checking Compressor Oil

The compressor is a sealed unit in the refrigeration system. Any time the system is evacuated the oil quantity must be checked. Remove the filler plug and using the proper type dip stick, check the oil quantity. It should be maintained in the proper range using oil recommended by the manufacturer. After adding oil, replace the filler plug and recharge the system.

CABIN PRESSURIZATION OPERATIONAL CHECKS

Two operational checks can be performed on a cabin air conditioning and pressurization system. The first is a general operational check of the complete system, designed to ensure the proper operation of each major system component as well as the complete system. The second is a cabin pressurization check designed to check the cabin for airtightness.

To operationally check the air conditioning system, either operate the engines or provide the necessary ground support equipment recommended by the aircraft manufacturer.

With system controls positioned to provide cold air, ensure that cold air is flowing from the cabin distribution outlets. Position the system controls to provide heated air and check to see that there is an increase in the temperature of the airflow from the distribution outlets.

Checking the cabin pressurization system consists of the following: (1) A check of pressure regulator operation, (2) a check of pressure relief and dump valve operation, (3) a cabin static pressure test, and (4) a cabin dynamic pressure test.

To check the pressure regulator, connect an air test stand and a monometer (a gage for measuring pressure, usually in inches of Hg) to the appropriate test adapter fittings. With an external source of electrical power connected, position the system controls as required. Then pressurize the cabin to 7.13 in. Hg, which is equivalent to 3.5 p.s.i. The pressurization settings and tolerances presented here are for illustrative purposes only. Consult the applicable maintenance manual for the settings for a particular make and model aircraft. Continue to pressurize the cabin, checking to see that the cabin pressure regulator maintains this pressure.

The complete check of this pressure relief and dump valve consists of three individual checks. First, with the air test stand connected to pressurize the cabin, position the cabin pressure selector switch to dump the cabin air. If cabin pressure decreases to less than 0.3 in. Hg (0.15 p.s.i.) through both the pressure relief and dump valves, the valves are dumping pressure properly. Second, using the air test stand, re-pressurize the cabin. Then position the manual dump valve to "dump." A lowering of the cabin pressure to 0.3 in. Hg (0.15 p.s.i.) and an airflow through the pressure relief and dump valve indicate that the manual dumping function of this valve is satisfactory. Third, position the master pressure regulator shutoff valve to "all off." (This position is used for ground testing only.) Then, using the air test stand, pressurize the cabin to 7.64 in. Hg (3.75 p.s.i.). Operation of the pressure relief and dump valves to maintain this pressure indicates that the relief function of the cabin pressure relief and dump valves is satisfactory.

The cabin static pressure test checks the fuselage for structural integrity. To perform this test, connect the air test stand and pressurize the fuselage to 10.20 in. Hg (5.0 p.s.i.). Check the aircraft skin exterior for cracks, distortion, bulging, and rivet condition.

Pressure checking the fuselage for air leakage is called a cabin pressure dynamic pressure test. This check consists of pressurizing the cabin to a specific

pressure using an air test stand. Then with a monometer, determine the rate of air pressure leakage within a certain time limit specified in the aircraft maintenance manual. If leakage is excessive, large leaks can be located by sound or by feel. Small leaks can be detected using a bubble solution or a cabin leakage tester.

A careful observation of the fuselage exterior, prior to its being washed, may also reveal small leaks around rivets, seams, or minute skin cracks. A telltale stain will be visible at the leak area.

CABIN PRESSURIZATION TROUBLESHOOTING

Troubleshooting consists of three steps: (1) Establishing the existence of trouble, (2) determining all possible causes of the trouble, and (3) identifying or isolating the specific cause of the trouble.

Troubleshooting charts are frequently provided in aircraft maintenance manuals for use in determining the cause, isolation procedure, and remedy for the more common malfunctions which cause the cabin air conditioning and pressurization systems to become inoperative or uncontrollable. These charts usually list the most common system failures. Troubleshooting charts are organized in a definite sequence under each trouble, according to the probability of failure and ease of investigation. To obtain maximum value, the following procedures are

Possible Cause	Isolation Procedure	Correction
(1) Trouble: Cabin temperature too high or too low (will not respond to control during "auto" operation).		
Defective temperature sensor.	Place system in manual operation and rotate air temperature control knob manually.	If system operates correctly, replace temperature sensor with one known to be operative and check system again in "auto" operation.
(2) Trouble: Cabin temperature too high or too low (will not respond to control during "auto" or manual operation).		
Defective temperature controller or refrigeration bypass valve inoperative.	With system being operated in manual position and the cabin air temperature control knob being cycled between "cold" and "hot" observe the valve position indicator (located on the valve).	If the valve is not opening and closing according to control settings, disconnect electrical plug from valve solenoid and check the power source. If the valve position indicates that the valve is opening and closing according to control settings, continue with the next troubleshooting item.

FIGURE 14-44. Troubleshooting an air cycle system.

recommended when applying a troubleshooting chart to system failures:

- (1) Determine which trouble listed in the table most closely resembles the actual failure being experienced in the system.
- (2) Eliminate the possible causes listed under the trouble selected, in the order in which they are listed, by performing the isolation procedure for each until the malfunction is discovered.
- (3) Correct the malfunction by following the instructions listed in the correction column of the troubleshooting chart.

Figure 14-44 is an example of the type of troubleshooting chart provided in the maintenance manual for an aircraft that uses an air cycle system.

OXYGEN SYSTEMS GENERAL

The atmosphere is made up of about 21% oxygen, 78% nitrogen, and 1% other gases by volume. Of these gases, oxygen is the most important. As altitude increases, the air thins out and air pressure decreases. As a result, the amount of oxygen available to support life functions decreases.

Aircraft oxygen systems are provided to supply the required amount of oxygen to keep a sufficient concentration of oxygen in the lungs to permit normal activity up to indicated altitudes of about 40,000 ft.

Modern transport aircraft cruise at altitudes where cabin pressurization is necessary to maintain the cabin pressure altitude between 8,000 and 15,000 ft. regardless of the actual altitude of the aircraft. Under such conditions, oxygen is not needed for the comfort of the passengers and crew. However, as a precaution, oxygen equipment is installed for use if cabin pressurization fails. Portable oxygen equipment may also be aboard for first-aid purposes.

With some of the smaller and medium size aircraft designed without cabin pressurization, oxygen equipment may be installed for use by passengers and crew when the aircraft is flown at high altitudes. In other instances where there is no installed oxygen system, passengers and crew depend on portable oxygen equipment stowed in convenient positions.

The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements, and, where applicable, the pressurization system. In some aircraft a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the larger transport aircraft. Many aircraft have a combination of both systems which may be augmented by portable equipment.

Continuous Flow System

In simple form a basic continuous-flow oxygen system is illustrated in figure 14-45. As shown in the illustration, with the line valve turned "on", oxygen will flow from the charged cylinder through the high-pressure line to the pressure-reducing valve, which reduces the pressure to that required at the mask outlets. A calibrated orifice in the outlets will control the amount of oxygen delivered to the mask.

The passenger system may consist of a series of plug-in supply sockets fitted to the cabin walls adjacent to the passenger seats to which oxygen masks can be connected, or it may be the "drop out" mask arrangement where individual masks are presented automatically to each passenger if pressurization fails. In both cases oxygen is supplied, often automatically, from a manifold. Any automatic control (e.g. barometric control valve) in the system can be overridden manually by a member of the crew.

Pressure-Demand System

A simple pressure-demand oxygen system is illustrated in figure 14-46. Note that there is a pressure-demand regulator for each crewmember, who can adjust the regulator according to his requirements.

PORTABLE OXYGEN EQUIPMENT

Typical portable oxygen equipment consists of a lightweight steel alloy oxygen cylinder fitted with a combined flow control/reducing valve and a pressure gage. A breathing mask, with connecting flexible tube and a carrying bag with the necessary straps for attachment to the wearer, completes the set.

The charged cylinder pressure is usually 1,800 p.s.i.; however, the cylinder capacities vary. A popular size for portable equipment is the 120-liter capacity cylinder.

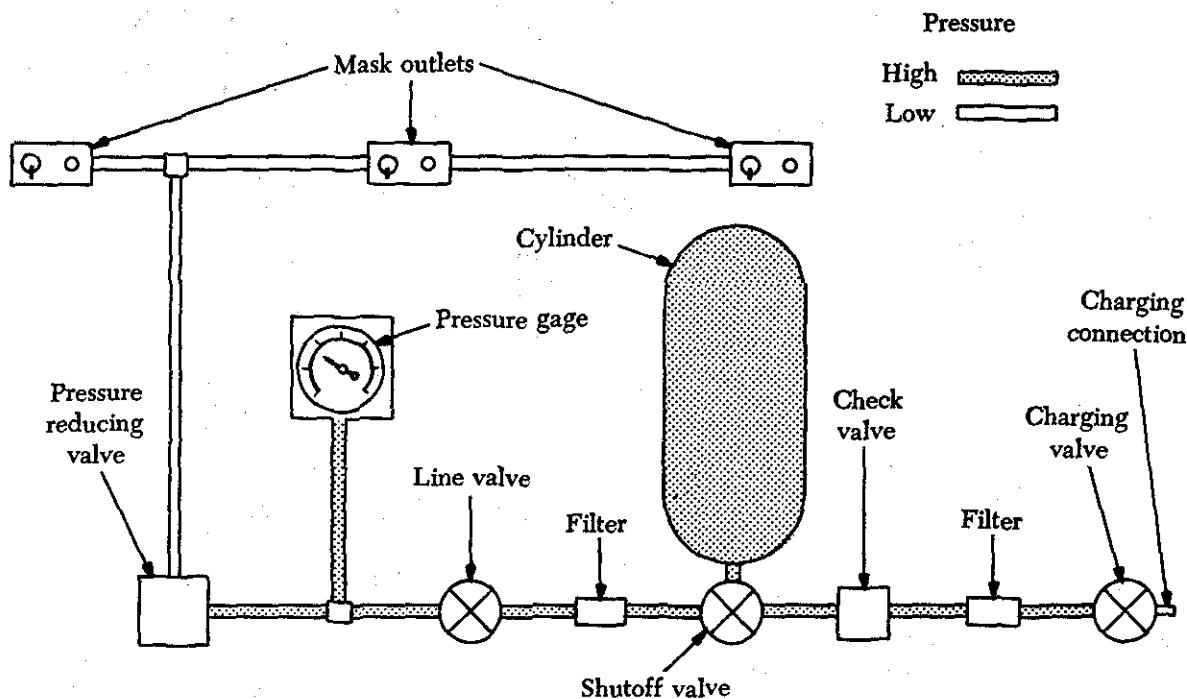


FIGURE 14-45. Continuous-flow oxygen system.

Depending on the type of equipment used, it is normally possible to select at least two rates of flow, normal or high. With some equipment three flow rate selections are possible, *i.e.*, normal, high, and emergency, which would correspond to 2, 4, and 10 liters per minute. With these flow rates a 120-liter cylinder would last for 60, 30, and 12 min., respectively.

SMOKE PROTECTION EQUIPMENT

In some instances there is a requirement to carry smoke protection equipment for use by a member of the crew in a smoke or fume-laden atmosphere. Smoke protection equipment consists of a special smoke protection facial mask with eye protection in the form of a clear-vision visor, together with the necessary oxygen supply hose and head straps. Some are designed for use with oxygen from the aircraft oxygen system, and others are self-contained portable equipment.

OXYGEN CYLINDERS

The oxygen supply is contained in either high-pressure or low-pressure oxygen cylinders. The high-pressure cylinders are manufactured from heat-treated alloy, or are wire wrapped on the out-

side surface, to provide resistance to shattering. All high-pressure cylinders are identified by their green color and have the words "AVIATORS' BREATHING OXYGEN" stenciled lengthwise in white, 1-in. letters.

High-pressure cylinders are manufactured in a variety of capacities and shapes. These cylinders can carry a maximum charge of 2,000 p.s.i., but are normally filled to a pressure of 1,800 to 1,850 p.s.i.

There are two basic types of low-pressure oxygen cylinders. One is made of stainless steel; the other, of heat-treated, low-alloy steel. Stainless steel cylinders are made nonshatterable by the addition of narrow stainless-steel bands that are seam-welded to the body of the cylinder. Low-alloy steel cylinders do not have the reinforcing bands but are subjected to a heat treatment process to make them nonshatterable. They have a smooth body with the word "NONSHATTERABLE" stenciled on them.

Both types of low-pressure cylinders come in different sizes and are painted light yellow. This color indicates that they are used for low-pressure oxygen only. The cylinders may carry a maximum charge of 450 p.s.i., but are normally filled to a pressure of

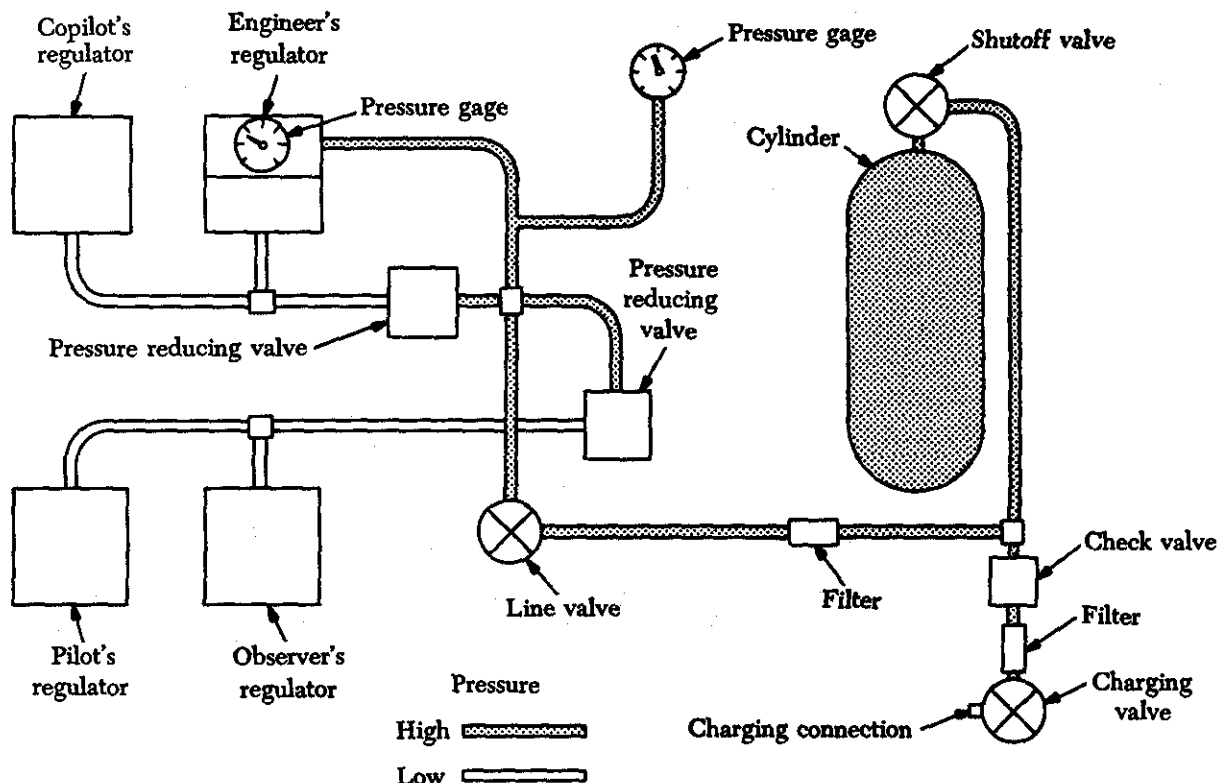


FIGURE 14-46. Typical pressure-demand oxygen system.

from 400 to 425 p.s.i. When the pressure drops to 50 p.s.i., the cylinders are considered empty.

The cylinders may be equipped with either of two types of valves. One type used is a self-opening valve which is automatically opened when the self-opening valve coupling assembly attached to the oxygen tubing is connected to the valve outlet. This coupling unseats a check valve, allowing oxygen from the cylinder to fill the oxygen system under high pressure. The other type is a hand-wheel, manually operated valve. This valve should be safety wired in the "full on" position when the cylinder is installed in the aircraft. This valve should be closed when removing or replacing parts of the oxygen system and when the cylinder is to be removed from the aircraft. Cylinders are often provided with a disk designed to rupture if cylinder pressure rises to an unsafe value. The disk is usually fitted in the valve body and vents the cylinder contents to the outside of the aircraft in the event of a dangerous pressure rise.

SOLID STATE OXYGEN SYSTEMS

Emergency supplemented oxygen is a necessity in any pressurized aircraft flying above 25,000 ft.

Chemical oxygen generators can be used to fulfill the new requirements. The chemical oxygen generator differs from the compressed oxygen cylinder and the liquid oxygen converter in that the oxygen is actually produced at the time of delivery.

Solid-state oxygen generators have been in use for a number of years, dating back to 1920, when it was first used in mine rescues. During World War II the Japanese, British and Americans, all worked to develop oxygen generators for aircraft and submarines.

In figure 14-47, 120 standard cubic feet of oxygen (10 lbs.) is shown schematically in the number of cubic inches of space it would occupy as a gas, a liquid or a solid. In figure 14-48, the necessary hardware to install and operate the system has been included in the size and weight measurements. A close comparison of these values makes it apparent that the solid state oxygen generator system is the most efficient space wise. Likewise less equipment and maintenance is required for solid state oxygen converters. Integrity inspection is the only requirement until actual use is implemented.

Solid state describes the chemical source, sodium chlorate, formula NaClO_3 . When heated to 478°F , sodium chlorate releases up to 45% of its weight as gaseous oxygen. The necessary heat for de-

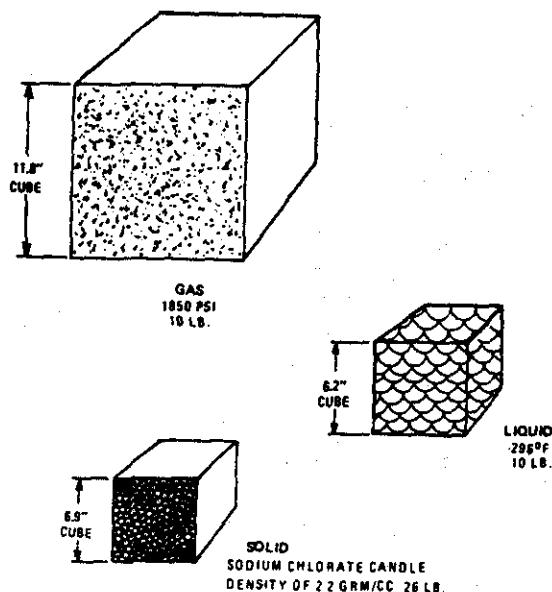


FIGURE 14-47. Volume comparison.

composition of the sodium chlorate is supplied by iron which is mixed with the chlorate.

The Oxygen Generator

Figure 14-49 illustrates a schematic representation of a basic oxygen generator. The center axial position is occupied by a core of sodium chlorate, iron, and some other ingredients mixed together and either pressed or cast into a cylindrical shape. This item has been popularly referred to as an oxygen candle, because when it is ignited at one end, it burns progressively in much the same manner as a candle or flare. Surrounding the core is porous packing. It supports the core and filters salt particles from the gas as it flows toward the outlet. A chemical filter and particulate filter at the outlet end of the container provide final clean up of the gas so that the oxygen delivered is medically pure breathing oxygen. An initiation device is an integral part of the package. This may be either a mechanical percussion device or an electric squib. The choice depends on the application. The entire assembly is housed in a thin shelled vessel. Often included is a layer of thermal insulation on the inside shell, a check valve seal on the outlet, and a relief valve to protect against an inadvertent over-pressure condition.

In operation, the burning is initiated at one end of the core by activating the squib or percussion device. Oxygen evolution rate is proportional to the cross sectional area of the core and the burn rate. The burn rate is determined by the concentration of fuel in the chlorate. In certain cases,

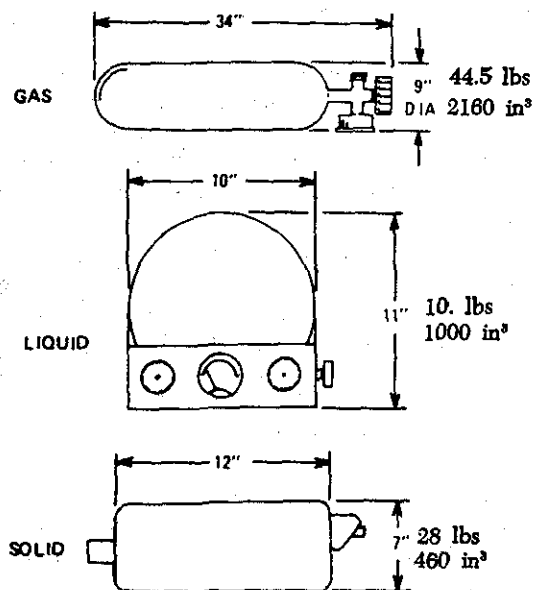


FIGURE 14-48. Weight and volume comparison—gas, liquid and solid oxygen storage.

one end of the core is larger than the other. The purpose of this is to program a high oxygen evolution rate during the initial few minutes of burning such as is required for an emergency descent supply. Burning continues until the core is expended.

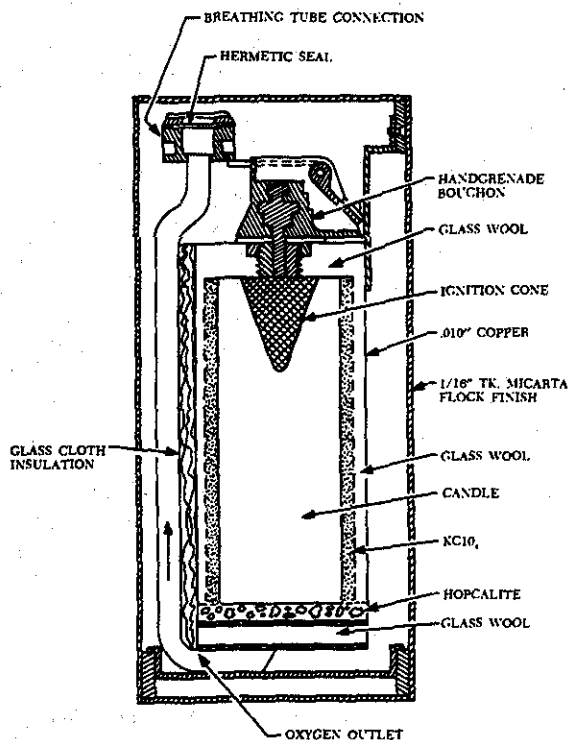


FIGURE 14-49. Apparatus for burning chlorate candles.

The simplicity of the process should be readily apparent; likewise, the limitations. There are no on/off valves and no mechanical controllers. Refill is accomplished by simply replacing, in total, the entire device. A limitation is that once the generator is initiated, flow is delivered at a predetermined rate, thus demand use is not very efficient.

In order to keep the process from consuming a great quantity of the oxygen, the quantity of iron is kept to a minimum. There is a tendency toward liberation of small amounts of chlorine. Barium peroxide, or barium dioxide, may be added by the manufacturer to provide an alkaline medium for removing the trace amounts of chlorine that may be present.

On a volume basis, which is extremely important in the aircraft installation, the storage capacity of oxygen in candles is about three times that of compressed gas.

A typical three outlet module for a 15 minute decompression emergency descent supply for a supersonic transport (25000 foot max. cabin altitude) weighs less than 0.9 pound and consists simply of a 2.1 inch diameter by 3.55 inch long stainless steel cylinder attached to three manifolded hose nipples. The cylinder contains the generator, initiator, salt, fume filter, enough insulation to keep the cylinder surface below 250° F. during burning, a pressure relief plug, and a temperature indicating paint spot for generator status visual inspection. The nipples contain orifices just small enough to assure essentially equal flow to all three masks.

The generators are inert below 400° F. even under severe impact. While reaction temperature is high and considerable heat is produced, the generators are insulated so that the outer surface of the cylinder is cool enough to avoid any fire hazard. The portable units may be held comfortably throughout the entire operation, as the heat generated is dissipated steadily over a long period of time. The same insulation works in reverse to delay initiation should a unit be subjected to an external fire. If such a fire is sufficiently prolonged to ignite the chlorate generator, oxygen production will be at a relatively low and continuous rate. In the simple continuous flow systems no pressure would be generated as all outlets would permit unrestricted flow of the oxygen, eliminating the intense jet torch effect of pressurized oxygen in fire.

Solid State vs. High Pressure Gaseous Oxygen

- Elimination of high pressure storage containers—saves weight.

- Elimination of distribution and regulation components—saves weight and maintenance.
- Simplification of individual distribution manifolds and drop-out mechanisms by the use of modular chlorate candle units.
- Improved reliability, hence safety by design of initiation circuitry, such that, an individual malfunction would not make other units inoperative (comparison here would be to ruptured lines, or high leakage in gaseous distribution systems).
- Simple, visual surveillance of each unit for condition of chlorate candle within the sealed container, by use of inspection window.
- Simple replacement of any unit, should it show any sign of deterioration, by plug-in cartridge, by relatively unskilled services crew; easily checked for installation and readiness for functioning from flight deck.
- Programmed oxygen release rates irrespective of the type of emergency.

OXYGEN PLUMBING

Tubing and fittings make up most of the oxygen system plumbing and connect the various components. All lines are metal except where flexibility is required. Where flexibility is needed, rubber hose is used.

There are several different sizes and types of oxygen tubing. The one most frequently used in low-pressure gaseous systems is made of aluminum alloy. Tubing made of this material resists corrosion and fatigue, is light in weight, and is easily formed. High-pressure gaseous supply lines are made from copper alloys.

Installed oxygen tubing is usually identified with color-coded tape applied to each end of the tubing, and at specified intervals along its length. The tape coding consists of a green band overprinted with the words "BREATHING OXYGEN" and a black rectangular symbol overprinted on a white background.

Oxygen System Fittings

Tube segments are interconnected or connected to system components by fittings. Tubing-to-tubing fit-

tings are designed with straight threads to receive flared tube connections. Tubing-to-component (cylinder, regulator, and indicator) fittings have straight threads on the tubing end and external pipe threads (tapered) on the other end for attachment to the component, as shown in figure 14-50.

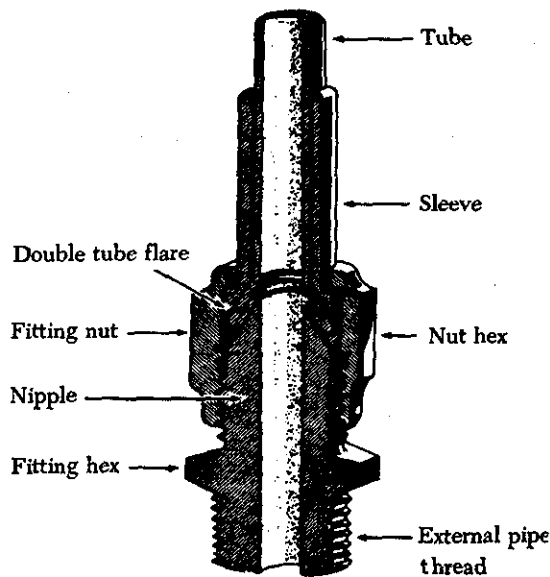


FIGURE 14-50. Sectional view of a typical oxygen system fitting.

Oxygen system fittings may be made of aluminum alloy, steel, or brass. These fittings may be either of two types, flared or flareless. A typical flared fitting is shown in figure 14-50. A flareless fitting is shown in figure 14-51.

The sleeve in a flareless fitting must be preset before final installation in a flareless seat. Presetting causes the cutting edge of the sleeve to grip the tube sufficiently to form a seal between the sleeve and the tubing. The end of the tubing bottoms on the seat of the flareless fitting to provide tube end support after installation.

To seal oxygen system tapered pipe thread connections and to prevent thread seizure, use only an approved thread compound. Never use a mixture containing oil, grease, or any other hydrocarbon on any fittings used in oxygen systems.

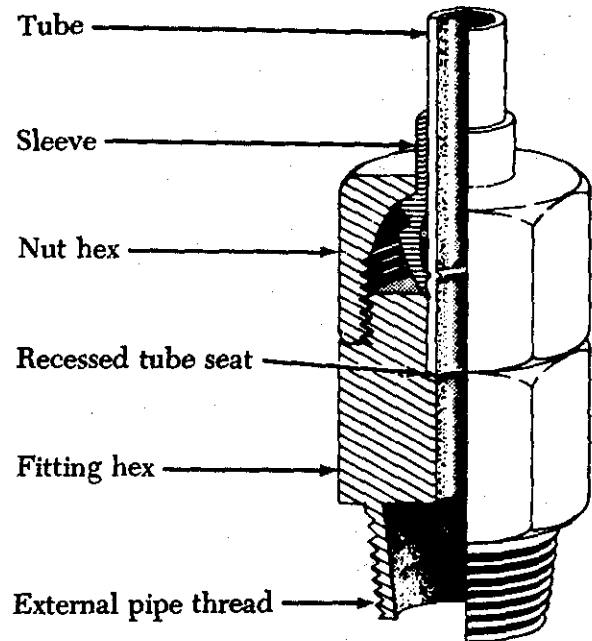


FIGURE 14-51. A typical flareless fitting.

Replacement Lines

The same cutting and bending methods described in Chapter 5, "Fluid Lines and Fittings," of AC 65-9A, Airframe and Powerplant Mechanics General Handbook, also apply to oxygen lines. As a general rule oxygen lines are double flared. The double flare makes the connection stronger and able to withstand more torque.

When installing a line, make sure there is proper clearance. The minimum clearance between oxygen plumbing and all moving parts should be 2 in. It is desirable to maintain a 6-in. clearance between oxygen tubing and electrical wires. When this is not possible, fasten all electrical wires securely with clips so that they cannot come to within 2 in. of the oxygen tubing.

OXYGEN VALVES

Five types of valves are commonly found in high-pressure gaseous oxygen systems. These are filler valves, check valves, shutoff valves, pressure reducer valves, and pressure relief valves. Low-pressure systems will normally contain only a filler valve and check valves.

Filler Valves

The oxygen system filler valve is located on most aircraft close to the edge of an access hatch or directly behind a cover plate in the skin. In either location, the valve is readily accessible for servicing. It is usually marked by a placard or a sign stenciled on the exterior, reading: "OXYGEN FILLER VALVE." There are two types of oxygen filler valves in use, a low-pressure filler valve and a high-pressure filler valve.

The low-pressure filler valve, figure 14-52, is used on systems equipped with low-pressure cylinders. When servicing a low-pressure oxygen system, push the recharging adapter into the filler valve casing. This unseats the filler valve and permits oxygen to flow from the servicing cart into the aircraft oxygen cylinders. The filler valve contains a spring-loaded locking device which holds the recharging adapter in place until it is released. When the adapter is removed from the filler valve, reverse flow of oxygen is automatically stopped by a check valve. A cap is provided to cover the filler opening and prevent contamination.

The high-pressure valve has a threaded fitting to receive the oxygen supply connector and a manual valve to control the flow of oxygen. To service an oxygen system that uses a high-pressure filler valve, screw the recharging adapter onto the aircraft filler valve. Open the manual valve on the filler valve and the servicing bottle. When recharging is completed, close the valves, remove the recharging adapter, and screw a valve cap on the valve to prevent contamination.

Check Valves

Check valves are installed in the lines between cylinders in all aircraft that have more than one storage cylinder. They are provided to prevent a reverse flow of oxygen or to prevent the loss of all oxygen as the result of a leak in one of the storage cylinders. Check valves permit the rapid flow of oxygen in only one direction. The direction of unrestricted flow is indicated by an arrow on the valves.

Of the two basic types of check valves commonly used, one type consists of a housing containing a spring-loaded ball. When pressure is applied to the

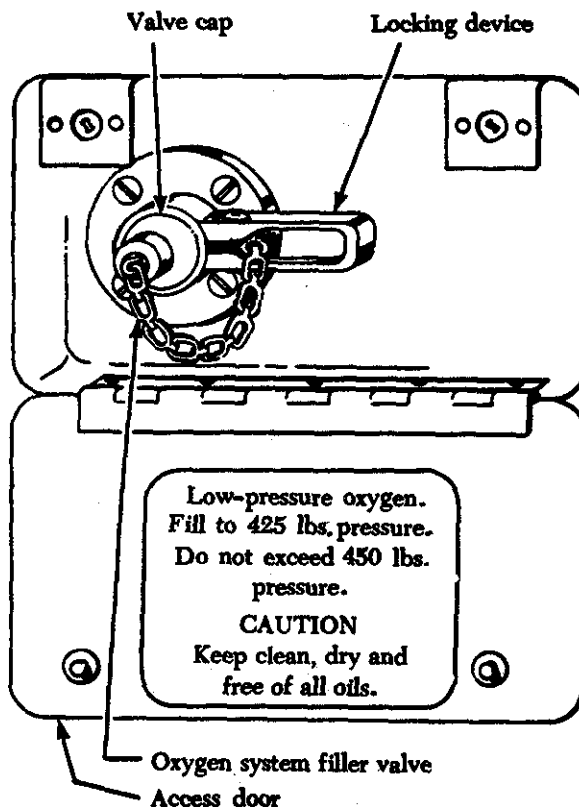


FIGURE 14-52. Low-pressure gaseous oxygen filler valve.

inlet side, the ball is forced against the spring, thus breaking the seal and allowing oxygen to flow. When pressure is equalized, the spring re-seats the ball, preventing any reverse flow of oxygen. The other type is a bell-mouthed hollow cylinder fitted with a captive ball in its bore. When pressure is applied at the bell-mouthed end (inlet), the ball will permit oxygen to flow. Any tendency of reverse flow causes the ball to move onto its seat, covering the inlet and preventing a reverse flow.

Shutoff Valves

Manually controlled two-position (on, off) shut-off valves are installed to control the flow of oxygen being emitted from a cylinder or a bank of cylinders. For normal operation, the knobs which control the valves are safetied in the "on" position. When necessary, such as changing a component, the appropriate valve can be closed. As a precaution, when opening a valve, the knob should be turned slowly to the "on" position. Otherwise, the sudden

rush of highly pressurized oxygen into a depleted system could rupture a line.

Pressure-Reducer Valves

In high-pressure oxygen systems, pressure-reducing valves are installed between the supply cylinders and the cockpit and cabin equipment. These valves reduce the high pressure of the oxygen supply cylinders down to approximately 300 to 400 p.s.i. required in the low-pressure part of the system.

Pressure-Relief Valves

A pressure-relief valve is incorporated in the main supply line of a high-pressure system. The relief valve prevents high-pressure oxygen from entering the system downstream of the pressure reducers if the reducer fails. The relief valve is vented to a blowout plug in the fuselage skin.

REGULATORS

Diluter-Demand Regulators

The diluter-demand regulator gets its name from

the fact that it delivers oxygen to the user's lungs in response to the suction of his own breath. To prolong the duration of the oxygen supply, the oxygen is automatically diluted in the regulator with suitable amounts of atmospheric air. This dilution takes place at all altitudes below 34,000 ft.

The essential feature of a diluter-demand regulator is a diaphragm-operated valve called the demand valve (figure 14-53), which opens by slight suction on the diaphragm during inhalation and which closes during exhalation. A reducing valve upstream from the demand valve provides a controlled working pressure. Downstream from the demand valve is the diluter control closing mechanism. This consists of an aneroid assembly (a sealed, evacuated bellows) which controls the air inlet valve. When the diluter lever is set in the position marked "normal oxygen," atmospheric air at ground level is supplied with very little oxygen added. As altitude increases, the air inlet is gradually closed by the bellows to give a higher concen-

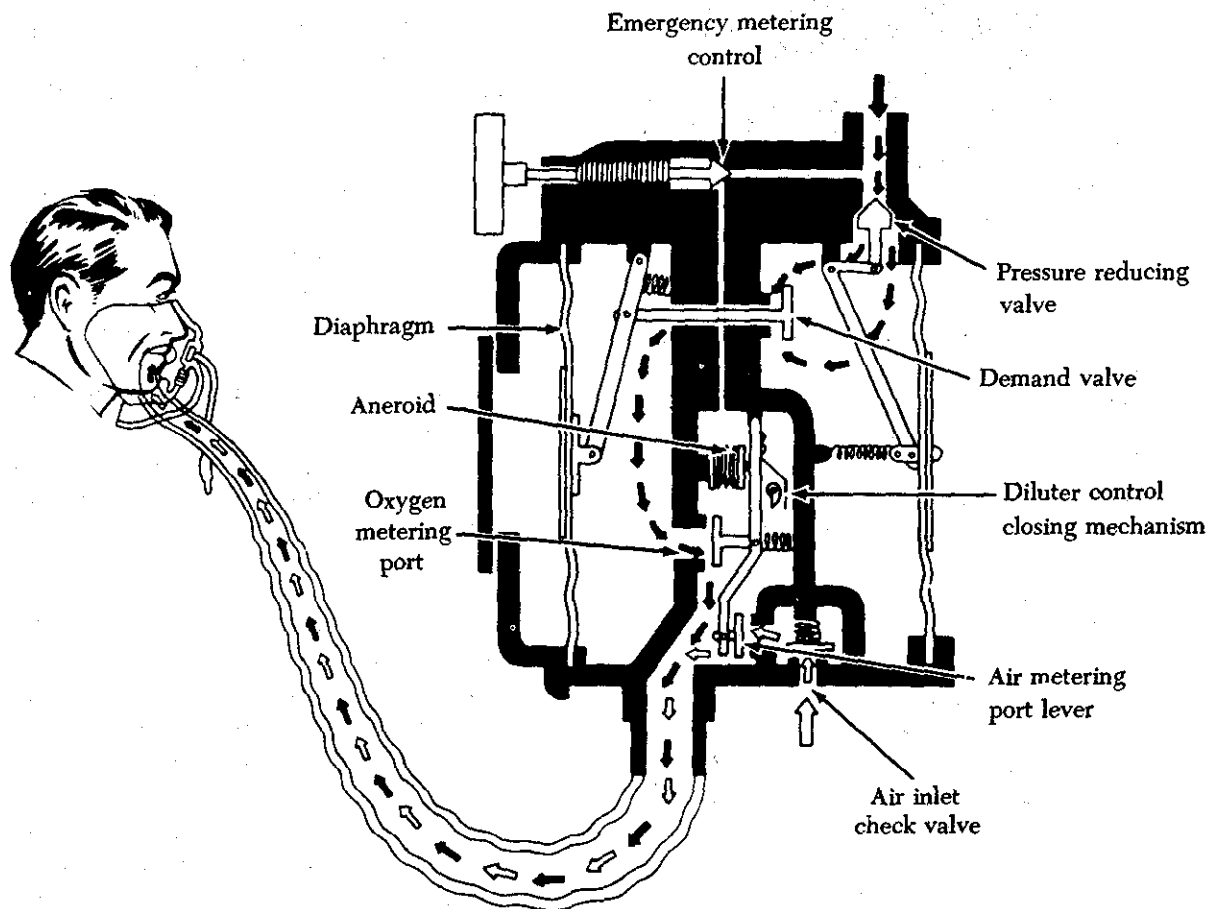


FIGURE 14-53. Schematic of a diluter-demand regulator.

tration of oxygen until at about 34,000 ft. the air inlet is completely closed and 100% oxygen is supplied. As altitude decreases, this process is reversed.

The diluter control as shown in figure 14-54, can be set by turning the lever to give 100% oxygen at any altitude. At moderate altitudes, however, this causes the oxygen supply to be consumed much more rapidly than normal. The diluter control should be set at "normal oxygen" for all routine operations. It can be set at "100 percent oxygen" for the following purposes: (1) Protection against exhaust gases or other poisonous or harmful gases in the aircraft, (2) to avoid the bends and chokes, and (3) to correct a feeling of lack of oxygen.

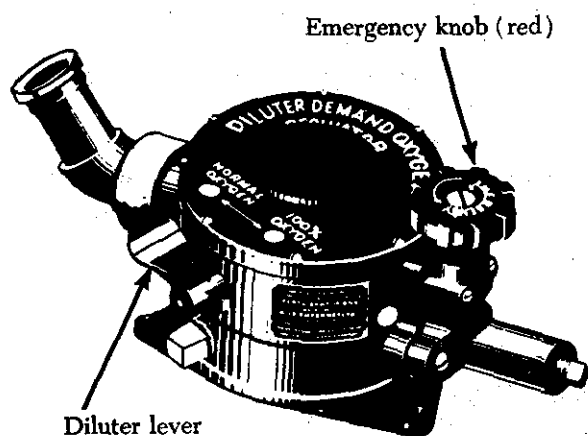


FIGURE 14-54. Diluter-demand regulator control.

The diluter-demand regulator is provided with an emergency valve, operated by a red knob (figure 14-54) on the front of the regulator. Opening this valve directs a steady stream of pure oxygen to the mask, regardless of altitude.

The following paragraphs illustrate a typical procedure for checking the operation of a diluter-demand regulator. First, check the oxygen system pressure gage, which should indicate between 425 and 450 p.s.i.; then check out the system using the following steps:

- (1) Connect an oxygen mask to each diluter-demand regulator.
- (2) Turn the auto-mix lever on the diluter-demand regulator to the "100 percent oxygen" position and listen carefully to make certain that no oxygen is escaping.
- (3) Breathe oxygen normally from the mask. The oxygen flowmeter should blink once for each breath. (Figure 14-55 shows a

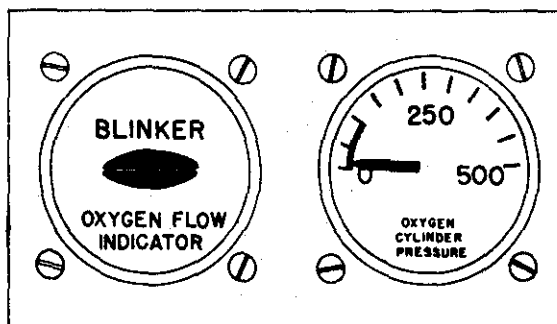


FIGURE 14-55. Flow indicator and pressure gage.

typical oxygen flowmeter and pressure gage.)

- (4) With auto-mix lever in "100 percent oxygen" position, place the open end of the mask-to-regulator hose against the mouth and blow gently into the hose. Do not blow hard, as the relief valve in the regulator will vent. There should be positive and continued resistance, if not, the diaphragm or some part of the air-metering system may be leaking.
- (5) Turn the auto-mix lever to "normal oxygen" position.
- (6) Turn the emergency valve on the diluter-demand regulator to the "on" position for a few seconds. A steady flow of oxygen should result, ceasing when the emergency valve is turned off.
- (7) Safety wire the emergency valve in "off" position with Federal Specification QQ-W-341, or equal, annealed copper wire, 0.0179-in. diameter.

Another type of diluter-demand regulator is the narrow panel type. This type regulator face (figure 14-56) displays a float-type flow indicator which signals oxygen flow through the regulator to the mask.

The regulator face also displays three manual control levers. A supply lever opens or closes the oxygen supply valve. An emergency lever is used to obtain oxygen under pressure. An oxygen selector lever is used for selecting an air/oxygen mixture or oxygen only.

Figure 14-57 illustrates how the narrow panel oxygen regulator operates. With the supply lever in the "on" position, the oxygen selection lever in the "normal" position, and the emergency lever in the "off" position, oxygen enters the regulator inlet.

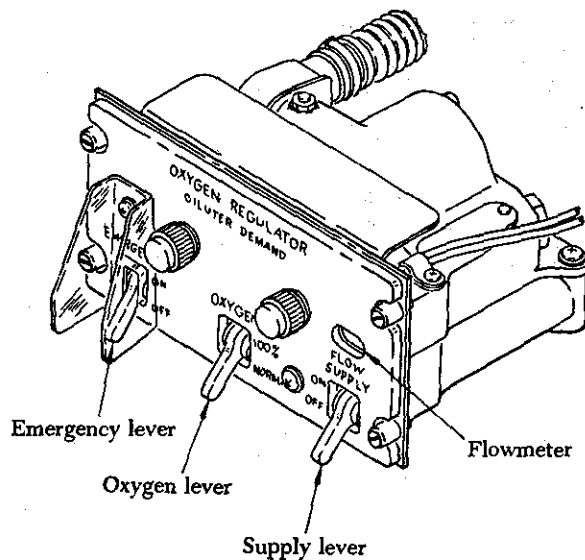


FIGURE 14-56. Typical narrow panel oxygen regulator.

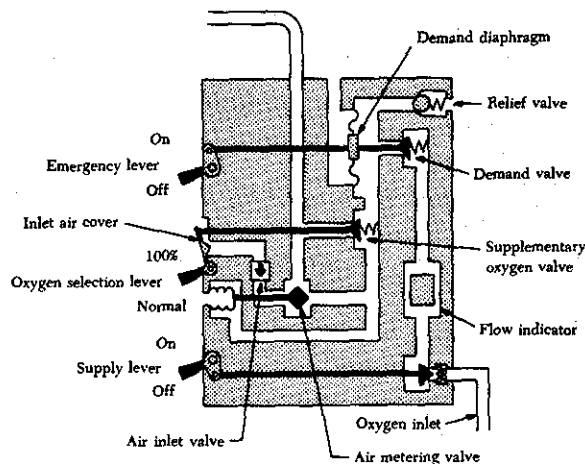


FIGURE 14-57. Schematic of a narrow panel oxygen regulator.

When there is sufficient differential pressure across the demand diaphragm, the demand valve opens to supply oxygen to the mask. This pressure differential exists during the user's inhalation cycle. After passing through the demand valve, the oxygen is mixed with air that enters through the air inlet port. The mixture ratio is determined by an aneroid-controlled air metering valve. A high oxygen ratio is provided at high altitudes and a high air ratio at lower altitudes. The air inlet valve is set to permit the airflow to begin at the same time as the oxygen flow.

The addition of air may be cut by turning the oxygen selection lever to "100%." When this lever is in "normal," air enters through the air inlet port, and the required amount is added to the oxygen to form the correct air/oxygen mixture.

Positive pressure at the regulator outlet may be obtained by turning the emergency lever to "on." This mechanically loads the demand diaphragm to provide positive outlet pressure.

Continuous-Flow Regulator

Continuous-flow regulators of the hand-adjustable and the automatic type are installed for the crew and passenger oxygen supply respectively.

The hand-adjustable, continuous-flow regulator delivers to the user's mask a continuous stream of oxygen at a rate that can be controlled. The system usually contains a pressure gage, a flow indicator, and a manual control knob for adjusting the oxygen flow. The pressure gage indicates the p.s.i. of oxygen in the cylinder. The flow indicator is calibrated in terms of altitude. The manual control knob adjusts the oxygen flow. The user adjusts the manual control knob until the altitude of the flow indicator corresponds to the cabin altimeter reading.

The automatic continuous-flow regulator is used in transport aircraft to supply oxygen automatically to each passenger when cabin pressure is equivalent to an altitude of approximately 15,000 ft. Operation of the system is initiated automatically by means of an electrically actuated device. The system can also be actuated electrically or manually should the automatic regulator malfunction.

Upon actuation, oxygen flows from the supply cylinders to the service units. A typical passenger service unit is shown in figure 14-58. During the

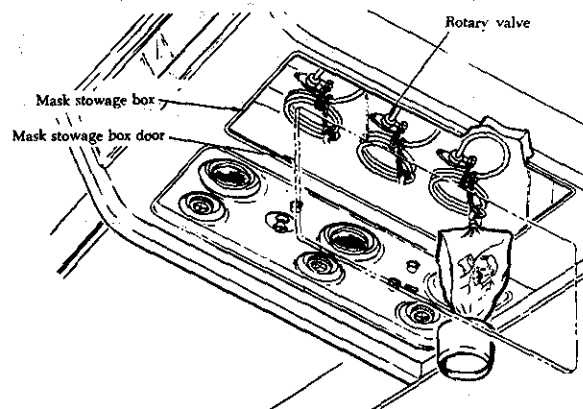


FIGURE 14-58. Typical passenger service unit.

first few seconds of oxygen flow, a pressure surge of 50 to 100 p.s.i. causes the oxygen mask box doors to open.

Each mask assembly then falls out and is suspended by the actuating attachment on the flexible tubing. The action of pulling the mask down to a usable position withdraws the outlet valve actuation pin, opening the rotary valve, allowing oxygen to flow to the mask.

OXYGEN SYSTEM FLOW INDICATORS

Flow indicators are used in oxygen systems to give visual indications that oxygen is flowing through the regulator. They do not show how much oxygen is flowing. Furthermore, their operation does not indicate that the user is getting enough oxygen.

In the blinker type indicator, figure 14-59, the eye opens and closes each time the user inhales and exhales. To check the flow indicator, set the diluter lever to "100% oxygen" and take several normal breaths from the mask-to-regulator hose. If the blinker opens and closes easily with each breath, it is in operating condition.

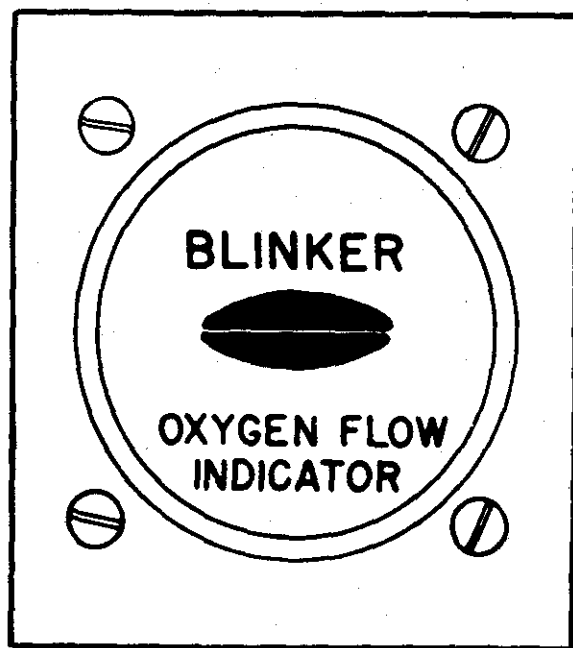


FIGURE 14-59. Oxygen flow indicator.

PRESSURE GAGES

Pressure gages are usually of the Bourdon tube type. Figure 14-60 shows the faces of two oxygen gages: (1) A low-pressure gage and (2) a high-pressure gage.

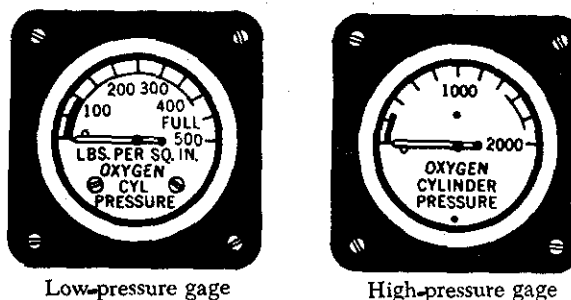


FIGURE 14-60. Oxygen pressure gages.

Because of their connection into a system, the gages do not necessarily show the pressure in each cylinder. If the system contains only one supply cylinder, the pressure gage will indicate cylinder pressure. In systems where several cylinders are interconnected through check valves, the gage will indicate the pressure of the cylinder having the highest pressure.

Immediately after the system has been filled, pressure gage accuracy can be checked by comparing the aircraft pressure gage with the gage on the servicing cart. On low-pressure systems, the aircraft gage should read within 35 p.s.i. of the 425 p.s.i. servicing cart pressure. The same check can be used for high-pressure systems, but servicing pressure is 1,850 p.s.i. and a tolerance of 100 p.s.i. is allowed. The tolerances shown for pressure gage accuracy are typical and should not be construed as applying to all oxygen systems. Always consult the applicable aircraft maintenance manual for the tolerances of a particular system.

OXYGEN MASKS

There are numerous types of oxygen masks in use which vary widely in design detail. It would be impractical to discuss all of the types in this handbook. It is important that the masks used be compatible with the particular oxygen system involved. In general, crew masks are fitted to the user's face with a minimum of leakage. Crew masks usually contain a microphone. Most masks are the oronasal type, which covers only the mouth and nose.

Large transport aircraft are usually fitted with smoke masks for each crew position. The smoke masks are installed in stowage containers within easy grasp of the individual. These masks provide crew protection in an emergency and are not used frequently like the demand and continuous-flow masks. Smoke mask equipment consists of a full-

face mask, a flexible breathing tube, and a coupling. The coupling connects to a demand regulator. A microphone is permanently installed in the mask.

Passenger masks, figure 14-61, may be simple, cup-shaped rubber moldings sufficiently flexible to obviate individual fitting. They may have a simple elastic head strap or they may be held to the face by the passenger.

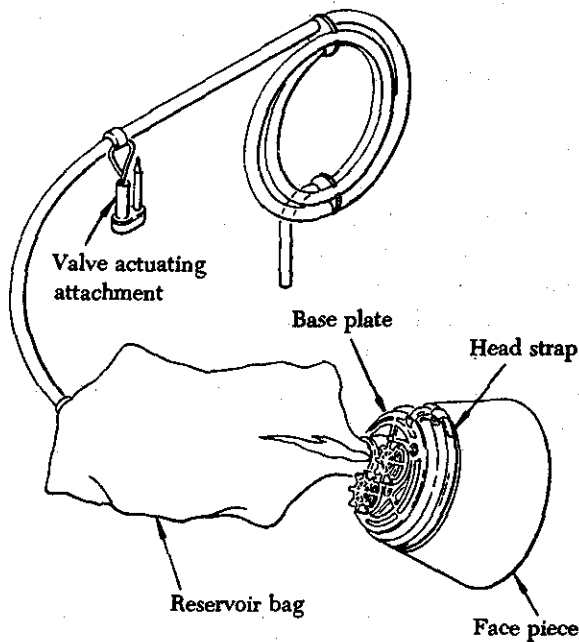


FIGURE 14-61. Passenger oxygen mask.

All oxygen masks must be kept clean. This reduces the danger of infection and prolongs the life of the mask. To clean the mask, wash it with a mild soap and water solution and rinse it with clear water. If a microphone is installed, use a clean swab, instead of running water, to wipe off the soapy solution.

The mask must also be disinfected. A gauze pad, which has been soaked in a water solution of merthiolate can be used to swab out the mask. This solution should contain one-fifth teaspoon of merthiolate per quart of water. Wipe the mask with a clean cloth and air dry.

SERVICING GASEOUS OXYGEN SYSTEMS

The servicing procedures for a gaseous oxygen system depend upon the type of system. Before charging an aircraft system, consult the aircraft manufacturer's maintenance manual. Precautions such as purging the connecting hose before coupling to the aircraft filler valve, avoiding overheating caused by too rapid filling, opening cylinder

valves slowly, and checking pressures frequently during charging should be considered.

The type of oxygen to be used, the safety precautions, the equipment to be used, and the procedures for filling and testing the system must be observed.

Gaseous breathing oxygen used in aircraft is a special type of oxygen containing practically no water vapor and is at least 99.5% pure. While other types of oxygen (welder, hospital) may be pure enough, they usually contain water, which might freeze and block the oxygen system plumbing especially at high altitudes.

Gaseous breathing oxygen is generally supplied in 220- to 250-cu. ft. high-pressure cylinders. The cylinders are identified by their dark green color with a white band painted around the upper part of the cylinder. The words "OXYGEN AVIATORS' BREATHING" are also stenciled in white letters, lengthwise along the cylinders.

Oxygen Service Safety

Gaseous oxygen is dangerous and must be handled properly. It causes flammable materials to burn violently or even to explode. Listed below are several precautionary measures to follow:

- (1) Tag all reparable cylinders that have leaky valves or plugs.
- (2) Don't use gaseous oxygen to dust off clothing, etc.
- (3) Keep oil and grease away from oxygen equipment.
- (4) Don't service oxygen systems in a hangar because of the increased chances for fire.
- (5) Valves of an oxygen system or cylinder should not be opened when a flame, electrical arc, or any other source of ignition is in the immediate area.
- (6) Properly secure all oxygen cylinders when they are in use.

Gaseous Oxygen Servicing Trailers

Even though several types of servicing trailers are in use, each recharging system contains supply cylinders, various types of valves, and a manifold that connects the high-pressure cylinders to a purifier assembly. In the purifier assembly, moisture is removed from the oxygen. Coarse particles are trapped in the filter before reaching a reducing valve. The reducing valve has two gages which are used to monitor inlet and outlet pressures respectively. The reducing valve also has an adjusting screw for regulating the outlet pressure. This pres-

sure is discharged into a flexible hose which connects to the charging valve and the adapter. The charging valve controls oxygen flowing away from the servicing trailer, and the adapter connects the recharging equipment to the aircraft filler valve.

On many aircraft a chart is located adjacent to the filler valve which shows the safe maximum charging pressure for the ambient temperature. This must be observed when charging the system.

It is common practice to have a warning placard cautioning against using oil or grease on the filler connections. Oxygen ground equipment should be maintained to a standard of cleanliness comparable to that of the aircraft system.

Leak Testing Gaseous Oxygen Systems

This test is performed at different times, depending on the inspection requirements for the particular type of aircraft. The system is allowed to cool, usually 1 hr., after filling before the pressures and temperatures are recorded. After several hours have elapsed, they are recorded again. Some manufacturers recommend a 6-hr. wait, others a 24-hr. wait. The recorded pressures are then corrected for any change in temperature since filling. Figure 14-62 is typical of the graphs provided in the aircraft main-

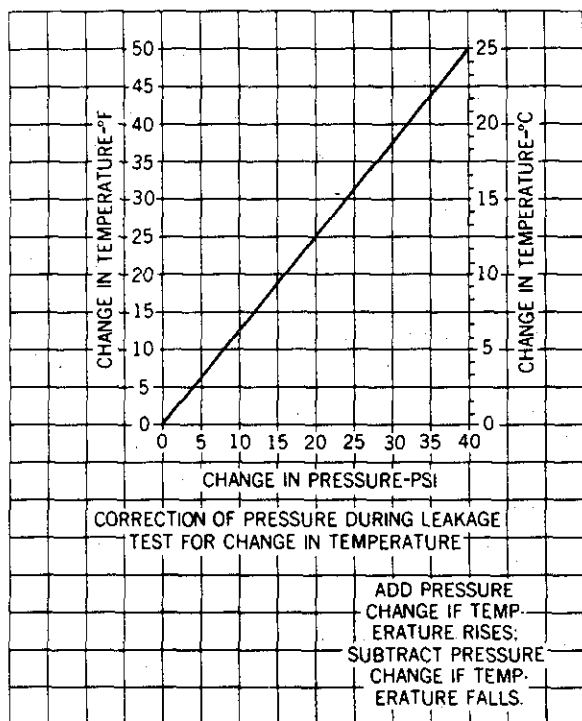


FIGURE 14-62. Pressure/temperature correction chart.

tenance manual to aid in making pressure/temperature corrections.

As an example for using the chart, assume that the oxygen system was recently charged. An hour later, the oxygen pressure gage read 425 p.s.i. at a temperature of 72° F. When the pressure gage was read 6 hrs. later, the pressure was 430 p.s.i. with a temperature of 79° F. By referring to figure 14-57, we see that the 7° temperature rise should have caused the pressure to increase 5 p.s.i., making the pressure gage read 430 p.s.i.

When oxygen is being lost from a system through leakage, the gage reading will be less than shown on the pressure/temperature correction chart. Leakage can often be detected by listening for the distinct hissing sound of escaping gas. If the leak cannot be located by listening, it will be necessary to soap-test all lines and connections with a castile soap and water solution or specially compounded leak-test material. To make this check, apply the test solution to areas suspected of leakage. Watch for bubbles. Make the solution thick enough to adhere to the contours of the fittings.

Any leak no matter how small must be found and repaired. A small leak may not cause trouble but if leak continues over a period of time, the surroundings and atmosphere become saturated. Such conditions are especially dangerous because personnel may not be aware that oxygen-enrichment exists. Oxygen-enriched conditions are almost always present in poorly ventilated areas.

NO ATTEMPT SHOULD BE MADE TO TIGHTEN A LEAKING FITTING WHILE THE SYSTEM IS CHARGED.

Draining the Oxygen System

When it is necessary to drain the system, it can be done by inserting a filler adapter into the filler valve and opening the shutoff valves. Do not drain the system too rapidly as this will cause condensation within the system. An alternate method of draining the system is opening the emergency valve on the demand oxygen regulator. Perform this job in a well-ventilated area and observe all fire precautions.

Cleaning the Oxygen System

Always keep the external surfaces of the components of the oxygen system, such as lines, connections, and mounting brackets, clean and free of corrosion and contamination with oil or grease. As a cleaning agent, use anhydrous (waterless) ethyl alcohol, isopropyl alcohol (anti-icing fluid),

or any other approved cleaner. If mask-to-regulator hoses are contaminated with oil or grease, the hoses should be replaced.

Cleaning Compound, Oxygen System

An approved cleaning formula for use on oxygen systems is available. This mixture of chlorinated, fluorinated hydrocarbons (freon) and isopropyl alcohol is safe for cleaning oxygen system components in aircraft, and for rinsing, flushing, and cleaning oxygen lines. Skin contact and prolonged inhalation of vapors should be avoided.

Purging the Oxygen System

An oxygen system needs to be purged if: (1) It has been depleted and not re-charged within 2 hrs., (2) if any line or component is replaced, requiring the draining or opening of the system for more than 2 hrs., or (3) it is suspected that the system has been contaminated.

The main cause of contamination in the system is moisture. Moisture in the system may be due to damp charging equipment. In very cold weather the small amount of moisture contained in breathing oxygen can cause contamination, due to repeated charging.

Although the introduction of moisture into the aircraft oxygen system can be considerably reduced by using the correct charging procedure, cumulative condensation in the system cannot be entirely avoided. There have been instances where oxygen systems, unused for long periods, have developed an unpleasant odor which necessitated purging to clear the system of moisture.

The procedure for purging may vary somewhat with each aircraft model. Generally speaking, on aircraft having the filler lines and the distribution lines commonly connected to one end of the storage cylinder, the system can be purged by filling the system with oxygen and then draining it at least three times. On aircraft that have the filler lines connected on one end of the cylinder and distribution lines connected to the opposite end of the cylinder, purge the system as follows: With all the regulator emergency valves open, pass oxygen at a pressure of 50 p.s.i. at the filler valve through the system for at least 30 min. Perform this job in a well-ventilated area and observe all fire precautions.

Dry nitrogen and/or dry air may also be used to purge oxygen systems. All open lines must be capped after use, also the system lines must be purged of the nitrogen by use of oxygen.

PREVENTION OF OXYGEN FIRES OR EXPLOSIONS

Many materials, particularly oils, grease, and non-metallic materials, are likely to burn when exposed to oxygen under pressure. To avoid fire or an explosion it is essential that all oxygen equipment be kept clean and free from oil or grease.

An oxygen fire or explosion depends on a combination of oxygen, a combustible material, and heat. The danger of ignition is in direct ratio to the concentration of oxygen, the combustible nature of the material exposed to the oxygen, and the temperature of the oxygen and material. Oxygen itself does not burn but it supports and intensifies a fire with any combustible material.

When working on an oxygen system it is essential that the warnings and precautions given in the aircraft maintenance manual be carefully observed. In general, before any work is attempted on an oxygen system the following fire precautions should be taken:

- (1) Provide adequate fire-fighting equipment.
- (2) Display "NO SMOKING" placards.
- (3) Avoid checking aircraft radio or electrical systems.
- (4) Keep all tools and oxygen servicing equipment free from oil or grease.

Oxygen System Inspection and Maintenance

Oxygen system inspection and maintenance should be accomplished according to these precautionary measures and any in addition to the manufacturer's instructions.

1. Never attempt maintenance until oxygen supply is turned off.
2. Fittings should be unscrewed slowly to allow residual pressure to dissipate.
3. Plug or cap all open lines immediately.
4. Do not use masking tape to seal openings: use caps or plugs designed for that purpose.
5. Maintain at least 2 inches clearance between oxygen lines and all moving equipment/parts within the aircraft to prevent the possibility of wearing oxygen lines.
6. Maintain at least 2 inches clearance between oxygen lines and all electrical wiring in the aircraft.
7. Provide adequate clearance between oxygen lines and all hot ducts, conduits and equip-

ment to prevent heating of the oxygen system.

8. Maintain at least 2 inches clearance between oxygen lines and all oil, fuel, hydraulic, or other fluid lines to prevent contamination.

9. Do not use lubricants unless specifically approved for oxygen system use.

10. A pressure and leak check must be performed each time the system is opened for maintenance.